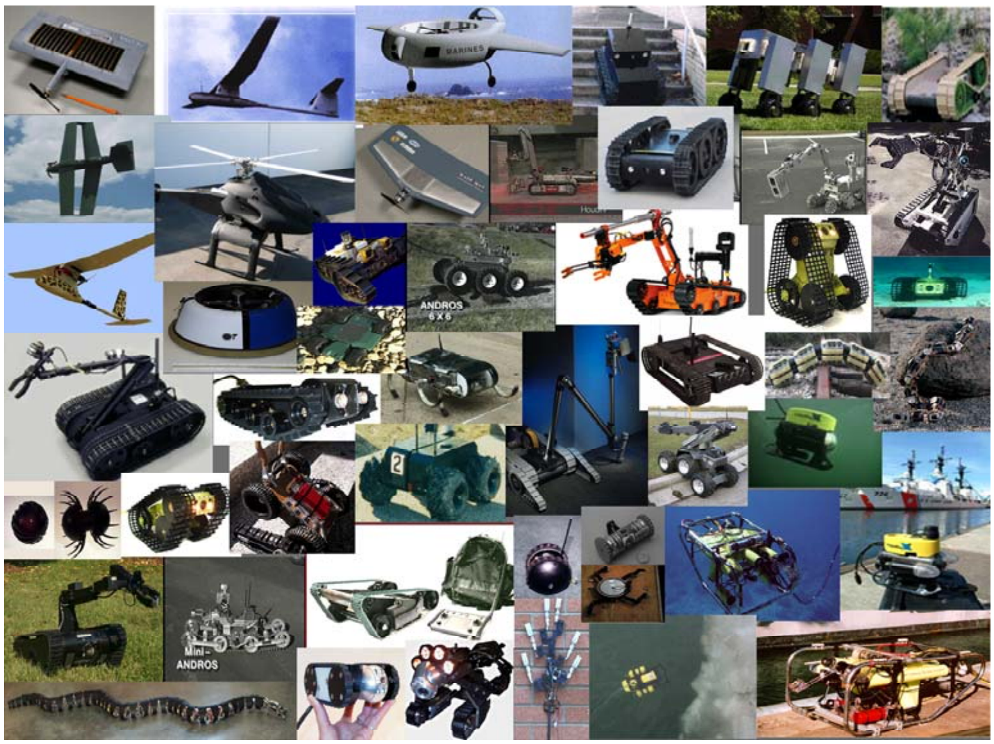
STATEMENT OF REQUIREMENTS FOR URBAN SEARCH AND RESCUE ROBOT PERFORMANCE STANDARDS



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REPORT INTRODUCTION

This report documents an initial set of requirements for the performance of robots that can support urban search and rescue (US&R) roles and tasks. These requirements were captured during three workshops held at NIST between November 2004 and February 2005, which included members from twenty FEMA Task Forces and the National Guard. This initial set of requirements will guide efforts to establish standard test methods for performance and use of US&R robots. As these efforts evolve, so will the set of working requirements. Updated versions of this report will be released periodically to document the process and publicize proposed test methods.

The structure of this document is as follows. Chapter 1 includes an introduction to the overall program, objectives, technical approach, and timeline for developing standard test methods based on captured performance requirements. Chapter 2 describes the requirements definition process. In this chapter, we present the methodology used to capture the initial set of requirements from the eventual users of US&R robots – the emergency responders – as well as the process used to determine the most widely applicable requirements. Chapter 3 lists candidate requirements to guide the first wave of test methods to be developed and introduced into the standardization process. Chapter 4 discusses sample test methods to help convey our approach. Chapter 5 discusses the next steps for the program. Chapters 6 and 7 discuss two associated efforts: classifications of robot capabilities and of building and collapse types. Chapter 8 introduces efforts to compile a compendium of robot capabilities, including the results of the standard performance tests developed under this program. The Appendices list additional reference information. Appendix A summarizes the participants in the workshops that defined the initial performance requirements. Appendix B contains the entire list of robot requirements resulting from the three workshops held with responders. Appendix C documents the emergency responders’ voting results for each requirement’s applicability to robot types and deployment scenarios generated to focus discussions. This data was the basis for selecting the initial subset of requirements to begin the process of developing standard test methods. Appendix D contains a two-part Glossary: US&R terminology and unmanned system terminology. These are included primarily to serve future expansions of this document.

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Chapter 1

STANDARD TEST METHODS FOR PERFORMANCE AND USE OF URBAN SEARCH AND RESCUE ROBOTS: PROGRAM BACKGROUND

In an effort to accelerate the development and deployment of robotic tools for urban search and rescue (US&R) responders, the National Institute of Standards and Technology (NIST) has begun the process of developing test methods for robotic technologies applied to US&R requirements. This effort will foster collaboration between US&R responders and technology developers to define performance metrics, generate standard test methods, and instrument test sites to capture robot performance in situationally relevant environments. The results of these standard performance tests will be captured in a compendium of existing and developmental robots with classifications and descriptors to differentiate particular robotic capabilities. This along with ongoing efforts to categorize situational US&R constraints such as building collapse types or the presence of hazardous materials will help responders match particular robotic capabilities to response needs. In general, these efforts will enable responders to effectively use robotic tools to enhance their effectiveness while reducing risk to personnel during disasters.

There are several possible ways to enhance the effectiveness of emergency responders through technology, but such solutions must be proven useful to the responder community prior to deployment in the field. Standardized test methods generated directly from responder requirements can ensure that applicable technologies are relatively easy to use, integrate efficiently into existing infrastructure, and provide demonstrable utility to response operations. Studies on ways to improve effectiveness of US&R and other responders have identified robots as potentially high-impact solutions. The Department of Homeland Security (DHS) Federal Emergency Management Agency (FEMA) and the National Institute of Justice (NIJ) co-sponsored an effort to identify and define functional requirements for new and/or improved technologies that meet the needs of both US&R teams as well as law enforcement agencies. The report [1] listed high priority needs, which included:

> “Reliable non-human, non-canine search and rescue systems - robust systems that combine enhanced canine/human search and rescue capabilities without existing weaknesses (i.e., robots)”

Another noteworthy report sponsored by DHS and the National Memorial Institute for the Prevention of Terrorism, “Project Responder: National Technology Plan for Emergency Response to Catastrophic Terrorism” [2], makes several mentions of robots as potentially useful to responders; but states that the technology needs to be further developed. It notes that specific requirements must first be defined. For example:

> “Sensor suite for robotics is a question of requirements, packaging and cost, not engineering. Radar can be made to work with robotic arms, etc. Requirements need to be generated to match the responder mission (weight constraints, power, endurance, standards, etc.).”
>
> “Development of requirements for applying the various sensor suites, platforms, robotics, batteries, etc. which already exist.”

Standard test methods generated from explicit requirements for US&R robots, with objective performance metrics and repeatable performance testing, will accelerate the development and deployment of mobile robotic tools for US&R responders. Currently, no such standards or performance metrics exist, although some guidelines for performance, capabilities, and human-system interactions have been identified [5,6].

In order to address this need, the DHS Science and Technology (S&T) Directorate initiated an effort in fiscal year 2004 with NIST to develop comprehensive standards to support development, testing, and certification of effective robotic technologies for US&R applications. These standards will address robot mobility, sensing, navigation, planning, integration into operational caches, and human system interaction. Such standards will allow DHS to provide guidance to local, state, and federal homeland security organizations regarding the purchase, deployment, and use of robotic systems for US&R applications.

The NIST team working toward developing these standard test methods is closely following the guidance provided by the above-mentioned studies. This effort builds on requirements voiced by US&R responders and focuses on fostering collaboration between the responders, robot vendors, and robot developers to generate consensus standard tests for task-specific robot capabilities and interoperability of components. Furthermore, the effort includes the development and administration of technology readiness level (TRL) assessment exercises. These exercises will generate statistically significant performance data for developmental and fieldable robotic systems.

In order to ensure the relevance and viability of robots to US&R, the program will follow a multi-year, iterative process, shown conceptually in Figure 1. The high-level effort areas and corresponding timeline are shown in Figure 2. To ensure that results are available as soon as possible, the effort is staged into two "waves," with the highest priority requirements that appear to be technologically attainable targeted for deployment in the FY06-FY08 timeframe. A second wave will address the remaining requirements; adding new requirements as necessary, while leveraging the standards process initiated in the first wave

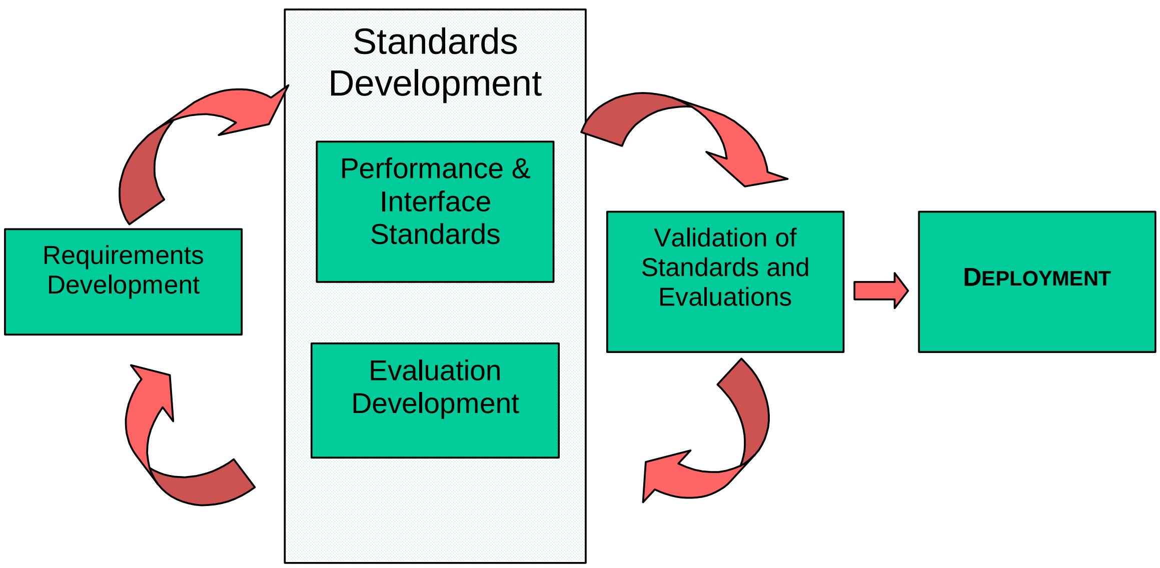


Figure 1: DHS US&R Robot Standards Process

The entire program is structured to ensure that the end-users' needs are captured and addressed. There will be annual workshops to monitor progress as well as several events that allow responders to work with emerging robotic equipment in realistic environments while helping to refine proposed test methods. These events are shown on the timeline as technology readiness level (TRL) assessment exercises. The requirements defined by the responders will be the foundation for constructing robot performance measures along with testing and evaluation (T&E) protocols that will provide reproducible methods for assessing and comparing the effectiveness of overall robotic systems and key components. Test sites will be developed that realistically evaluate these robot's capabilities, along with supporting measurement infrastructure to facilitate characterization of the test sites and to capture robot performance during test administration.

Ultimately, the goal is to have one or more sites certified to perform this program's standard test methods and provide ongoing robot performance testing. Initially, each site will focus on specific aspects of the overall robotic systems (mobility for example), to avoid issues of conformity between test sites. Finally, in recognition that these novel tools need to be integrated into existing responder operations, new standard operating procedures may be developed, along with corresponding training and deployment plans.

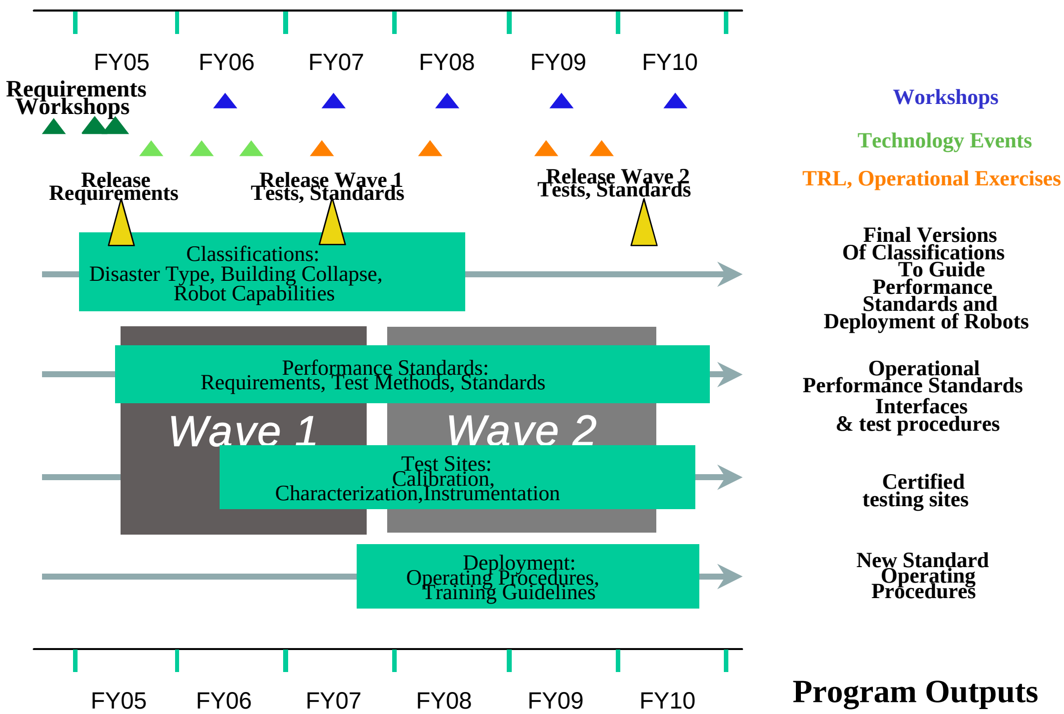


Figure 2: Timeline for DHS US&R Robot Standards Program

Overall Process and Rationale

This program will follow the same general approach used in the other DHS S&T standards development and implementation projects. For each component of US&R robots, guidelines for the performance requirements will be developed as a collaborative effort among users (subject matter experts), tool developers, and standards experts. Requirements and guidelines will be defined using information related to the capabilities – and the limitations – of the components, and on the conditions in which the component and system are expected to operate. The guidelines will be the foundation for constructing performance measures along with testing and evaluation protocols that will provide a reproducible method for assessing and comparing the effectiveness of each system component and of the overall robotic system supporting homeland security. Performance measures will encompass the following: basic functionality, adequacy and appropriateness for the task, interoperability, efficiency, and sustainability. The components of the robot systems include platforms, sensors, operator interfaces, software, computational models and analyses, communication, and information.

A national measurements and standards infrastructure for US&R robot software, hardware, and processes that supports the homeland security user group will be established. The primary objective of this infrastructure in its initial phase is the development of requirements, guidelines, performance metrics, test methods, certification, reassessment, and training procedures.

One of the key parts of the national measurements and standards infrastructure for homeland security hardware, software and processes is the development of consensus performance standard test methods. This project will leverage existing expertise by establishing a working relationship between these Standards Development Organizations (SDOs) and other federal agencies to develop consensus requirements and performance standard test methods for US&R robot products and processes. Information available from international efforts will also be evaluated for inclusion.

This process will build on existing approaches for testing US&R robots and related technologies. The national measurements and standards infrastructure will ultimately include common guidelines for federal, state and private sector test and evaluation laboratories for evaluating performance of US&R robot technologies against national consensus standards

The overall technical rationale for this program is summarized in Table 1. The high-level technical objectives generated in response to the program needs are listed in this table. The technical objectives were mapped onto major tasks within the program. The focus of this report is on the early phases of the program. An iterative development approach will be used to produce initial versions of performance metrics and standards as quickly as possible, and then refine them based on continuing input from the first responder community, researchers, and robot suppliers, and performance testing within representative environments.

The standards development cycle includes the following phases:

1) Requirements definition and prioritization (users, facilitated by NIST)
2) Draft standard test methods and metrics (users and developers, facilitated by NIST)
3) Refinement and validation of test methods and metrics (users and developers, facilitated by NIST)
4) Standards publication and dissemination (by SDOs)

Table 1: Rationale for Technical Approach

Needs	Solution
Characterizations of deployment environments and scenarios do not exist	- Identify/generate a taxonomy of building collapses and disaster scenarios (see Chapter 7) - Define robot performance requirements according to disaster/building taxonomy
Mobile robot technologies (hardware and software) need to be identified, directed toward real-world scenarios, and proven through objective testing	- Generate a taxonomy of robot technologies and capabilities (See Chapter 6) - Define performance requirements for physical platform, sensors, communications, power, locomotion, operator interface, and all other component technologies (See Chapters 2 & 3) - Develop standard performance metrics based on requirements above - Define test methodologies for evaluating performance of above components in representative environments (See Chapter 4) - Apply technology readiness level (TRL) assessment techniques to evaluate the maturity of components and systems (see Chapter 5)

	- Where relevant, define interface standards to develop - Define compliance tests for defined interfaces
Robots need to be integrated as tools in the disaster response infrastructure	- Identify strategy for integration into response infrastructure, FEMA tools caches, and maintenance schedules - Ensure that no conflicts with existing infrastructure arises (e.g. communications) - Define interface standards where appropriate - Develop compliance tests for defined interfaces
Robots need to be integrated into first responder operations	- Based on disaster taxonomy and robot performance definitions, develop new standard operating procedures - Provide training

Chapter 2

PERFORMANCE REQUIREMENTS DEFINITION

The process to define US&R robot performance requirements began by assembling a group of subject matter experts, primarily FEMA Task Force leaders and specialists. Representatives from most FEMA Task Forces participated in some or all three workshops held to define initial performance requirements for the robots. Appendix A lists the participants.

Urban search and rescue teams are comprised of a large number of individual specialists who perform specific functions. The search and rescue operation itself is divided into several phases, which are roughly sequential in order, although some may be carried out in parallel. Basic responsibilities during a rescue effort were identified as reconnaissance, primary search, structural assessment, stabilization, medical, rescue, monitoring, hazardous materials, and others. During the course of the first workshop, the working group identified two particular roles, reconnaissance and primary search, as the two highest priorities for applying robots.

To aid the process of defining requirements for US&R robots, different approaches were tried during the workshops. Initially, the responders defined several robot access categories to help focus the discussions: 2 inch bore hole, 24 inch triangular hole, doorway, and aerial, shown in Figure 3. The first three are based on current access methods used by responders. The aerial category was added since it seemed desirable for upper stories that are difficult to access otherwise.

Figure 3: Initial access categories: 2 inch bore hole, 24 inch triangular hole, doorway, and aerial.

The responders generated three scenarios to put the discussions into context, shown in Table 2. These scenarios were used to facilitate discussions and are not meant to be comprehensive. The responders were asked to develop specific robot requirements for each scenario, metrics to measure performance, and associated objective/threshold values they expect would be useful for those environments.

By the third workshop, a more detailed set of situations was needed to stimulate the responders to fully consider how the robots would be used in reality, and to make sure everyone was envisioning the same thing. Thirteen robot categories developed during prior robotics programs at the Defense Advanced Research Projects Agency (DARPA) and elsewhere were adopted to provide this focus. They are shown in Table 3. These are not necessarily meant to define specific robotic implementations desired for US&R, since it is premature to make these decisions. However, some of them may in fact provide reasonable approximations of robotic capabilities that will be identified by responders as “high priority” while being considered “fieldable” in the near term by developers. This combination of high priority and technical availability will be targeted for Wave 1 test methods.

Integrated product and process development (IPPD) methods and the Dynamic Insight© software tool were used to capture and document the requirements defined by responders. Dynamic Insight captures customer requirements in detail, including descriptions, objective values and thresholds, and how the requirements will be measured for conformance. Candidate technologies (in our case, robotic systems from particular vendors) can later be evaluated with respect to the requirements and the results will be highlighted through radar charts. Sample forms used to illustrate the level of detail possible using IPPD are shown in Figure 4. Figure 5 shows samples of radar charts that would be used to measure how well a particular solution addresses the main requirements categories (spokes) as well as the risk that technology poses in addressing each category's requirements. The risk is assessed by a panel of experts and developers who evaluate the maturity of the candidate technology among other criteria.

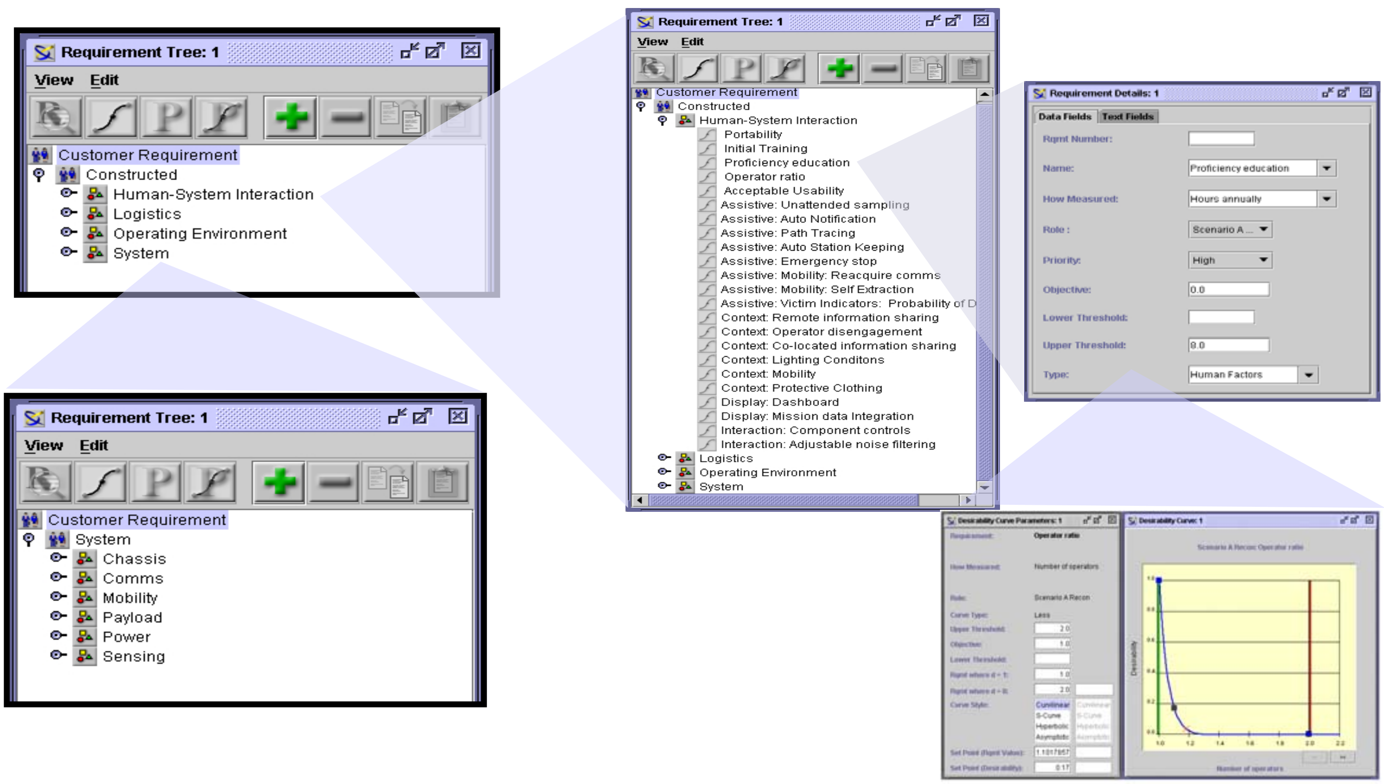


Figure 4: Hierarchical requirements capture using IPPD methods. These images illustrate the level of detail in the requirements capture. For each individual requirement several data points are captured: descriptions, metrics, priorities, performance objectives, acceptable thresholds, and desirability curves. Desirability curves capture the intent of the responders for the range between the threshold and the objective performance values for a given requirement.

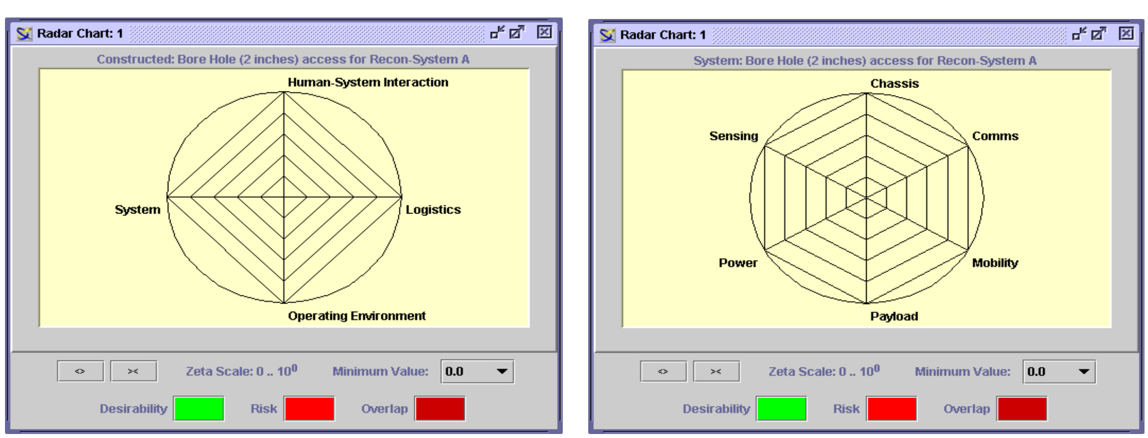


Figure 5: Radar charts for candidate solutions are measured against required performance objectives and thresholds to fill in major axes of chart. The risk associated with the technical solution, assessed by experts and developers, is the overlaid to show trade-offs of expected benefits versus risk.

Table 2: Scenarios

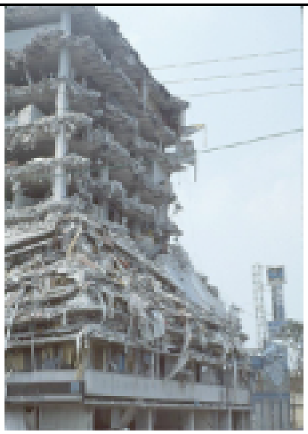
	Scenario A	Scenario B	Scenario C
Description	Upper stories of a multi-story pancake collapse	Subsurface voids	US&R Type II
Characteristics	Soft stories in the middle, undetermined stability, uneven terrain, sloped floor with holes, variable debris size, high hazmat potential, and poor visibility	Downwardly accessible void spaces, twisted/turning access (i.e., searchcam can't reach or turn necessary corners), variety of materials, complex orientations of support surfaces, sufficiently complex to cause spatial disorientation, hot, may be wet, high hazmat potential, and poor visibility	Rapid extraction of many non-ambulatory live victims from a contaminated (WMD / CBRNE) environment in a large urban area. This assumes that explosions or collapses have not compromised structures. Sample areas include malls, stadiums, several city blocks, etc. Teams may be pre-deployed.
Representative Image			

Table 3: Potential Robot or Deployment Categories

	Robot Category	Employment Role(s)	Deployment Method(s)	Tradeoffs
1.	Ground: Peek Robots	Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work	Tossed, chucked, thrown pneumatically, w/surgical tubing; marsupially deployed	Trade mobility, duration, sensing for increased expendability
2.	Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach Robots	Stairway & upper floor situational awareness; mitigation activities; stay behind monitoring	Backpacked; self driven; marsupially deployed	Experience form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant
3.	Ground: Non-collapsed Structure--Wide area Survey Robot	Long range, human access stairway & upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring	Backpacked; self driven; marsupially deployed	Experience form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant
4.	Ground: Wall Climbing Deliver Robots	Deliver Payloads to upper floors; provide expanded situational awareness when aerial platforms are unavailable or untenable	Placed; thrown pneumatically, w/surgical tubing; marsupially deployed	Trade payload capacity for vertical mobility and stable perching
5.	Ground: Confined Space, Temporary Shore Robots	Adaptive, temporary shoring; provide stay behind monitoring; victim triage & support	Placed: lowered via tether	Trade mobility and payload capacity for shoring capacity
6.	Ground: Confined Space Shape Shifters	Search; provide stay behind monitoring	Placed; lowered via tether	Trade payload capacity for confined space access

	Robot Category	Employment Role(s)	Deployment Method(s)	Tradeoffs
7.	Ground: Confined Space Retrieval Robots	Retrieve objects from confined spaces; provide stay behind monitoring	Placed; lowered via tether	Trade sensing capacity for manipulators, confined space access
8.	Aerial:High Altitude Loiter Robots	Provide overhead perspective & sit. awareness; provide HAZMAT plume detection; provide communications repeater coverage	Released: balloon or F/W; tethered LTAF (kite)	Trade penetration capacity for vertical perspective
9.	Aerial: Rooftop Payload Drop Robots	Payload delivery to rooftops; provide overhead perspective; provide communications repeater coverage	Launched F/W; tethered LTAF (kite)	Trade penetration capacity & loiter time for vertical drop
10.	Aerial: Ledge Access Robot	Object retrieval from upper floors; crowd control with a loudspeaker object attached, provide situational awareness	Launched Vertical Take-off and Landing (VTOL); VTOL	Trade simplicity, penetration capacity, loiter time for precise vertical drop
11.	Aquatic: Variable Depth Sub Robot	Structural inspection; leak localization/mitigation; object (body) recovery	Dropped into water; lowered via tether	Trade ground mobility for sub surface access & free swim capacity
12.	Aquatic: Bottom Crawler Robot	Water traverse; rapid current station keeping; object recovery	Driven across water; lowered via tether	Pursue amphibious mobility at cost of other performance
13.	Aquatic: Swift Water Surface Swimmer	Upstream access and station keeping; payload delivery; object recovery	Dropped into water; marsupially deployed	Pursue swift water capacity at cost of other performance

PERFORMANCE REQUIREMENTS DATA

The series of three requirements definition workshops produced a total of 103 requirements by the responders. The requirements fit into the major categories listed in Table 4. The individual requirements and a description of each are shown in Appendix B.

Table 4: Main Requirement Categories

Requirements Category	Number of Individual requirements	Category Definition
Human-System Interaction	23	Pertaining to the human interaction and operator(s) control of the robot
Logistics	10	Related to the overall deployment procedures and constraints in place for disaster response
Operating Environment	5	Surroundings and conditions in which the operator and robot will have to operate
System		Overall physical unit comprising the robot. This consists of the sub-components below
- Chassis	4	The main body of the robot, upon which additional components and capabilities may be added. This is the minimum set of capabilities (base platform).
- Communications	5	Pertaining to the support for transmission of information to and from the robot, including commands for motion or control of payload, sensors, or other components, as well as underlying support for transmission of sensor and other data streams back to operator
- Mobility	12	The ability of the robot to negotiate and move around the environment
- Payload	7	Any additional hardware that the robot carries and may either deploy or utilize in the course of the mission
- Power	5	Energy source(s) for the chassis and all other components on board the robot
- Sensing	32	Hardware and supporting software which sense the environment

ANALYSIS OF REQUIREMENTS DATA

In order to identify the most widely applicable requirements for our Wave 1 emphasis, the responders were asked to indicate in an electronic spreadsheet which requirements were applicable for each of the thirteen robot categories defined previously. Each Task Force was given a single spreadsheet (one vote) even if there were more than one representative from that Task Force in attendance. A total of thirteen Task Forces participated in this particular exercise.

The individual spreadsheets with the votes by each Task Force were collected into a single file, which was used as a starting point for statistical analyses. The initial summarization of the results was the totaling of the number of votes each requirement got for a given robot category. This was done by counting the non-zero cells across all the task force spreadsheets for a given requirement/robot category pairing. So, for example, the Human-System Interaction Requirement "Self Extraction" was deemed necessary by only 2 Task Forces in "peek robot" whereas 11 Task Forces thought it was a necessity for a "non-collapsed structure or wide area survey robot." Not surprisingly, some requirements showed wide variability with respect to the robot categories. The summary, which indicate the number of votes each requirement got for a given robot category, is shown in Appendix C.

Four key measures were computed for each requirement. For each of the 103 requirements, the following were calculated looking across the votes by all 13 task forces:

1. The average number of robot categories for which the requirement was considered applicable
2. The median number of robot categories for which the requirement was considered applicable
3. The maximum number of robot categories for which the requirement was considered applicable
4. The minimum number of robot categories for which the requirement was considered applicable

Two additional global measures were computed. The grand mean (average) of robot categories for all requirements was computed to be 8.105. The median number of robot categories to which each requirement was voted applicable was 8.

An initial pass at filtering the data based on a joint criterion yielded the 21 most commonly applicable requirements. Let Y be the score, which is the number of robot categories that a requirement was voted as being applicable to. The four factors comprising the joint criterion are described below:

1. $\overline{Y_i} \geq \overline{\overline{Y}}$

   The average of the ith requirement Y is greater than or equal to the grand average for the total dataset. This means that a requirement must have been found applicable to at least 8.105 different robot categories.

2. $\mathrm{Med}(Y_i) \geq 10$

   The median for the ith requirement is at least in the double digits. This means that a requirement's median number of robot categories to which it was voted applicable was more than 10.

3. $\mathrm{Min}(Y_i) \geq 8$

   The minimum for the ith requirement is at least 8. This means that the minimum number of robot categories that a requirement was found to be applicable to by any task force must be greater than 8.

4. $\mathrm{Max}(Y_i) \geq 12$

   The maximum for the ith requirement is at least 12. This means that the maximum number of robot categories was found to be applicable to by any task force must be greater than 12.

The requirements that met criteria 1 – 4 were selected as candidates for Wave 1 of the testing protocols and standardization process. The number of requirements selected by this method was 21. The results are shown in Table 5 in the next Chapter.

The results of the analysis are shown graphically in the charts in Figures 6 and 7. The y axis represents the number of robots/situations to which the teams thought the particular requirement was pertinent.

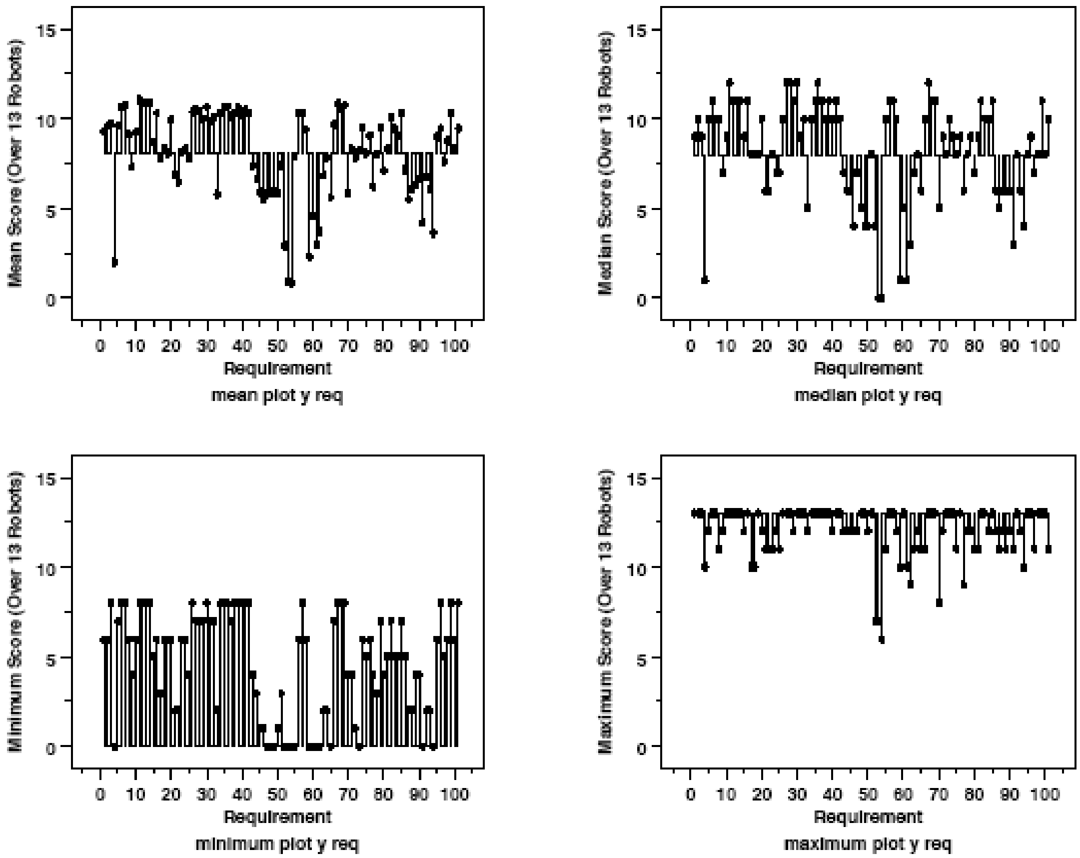
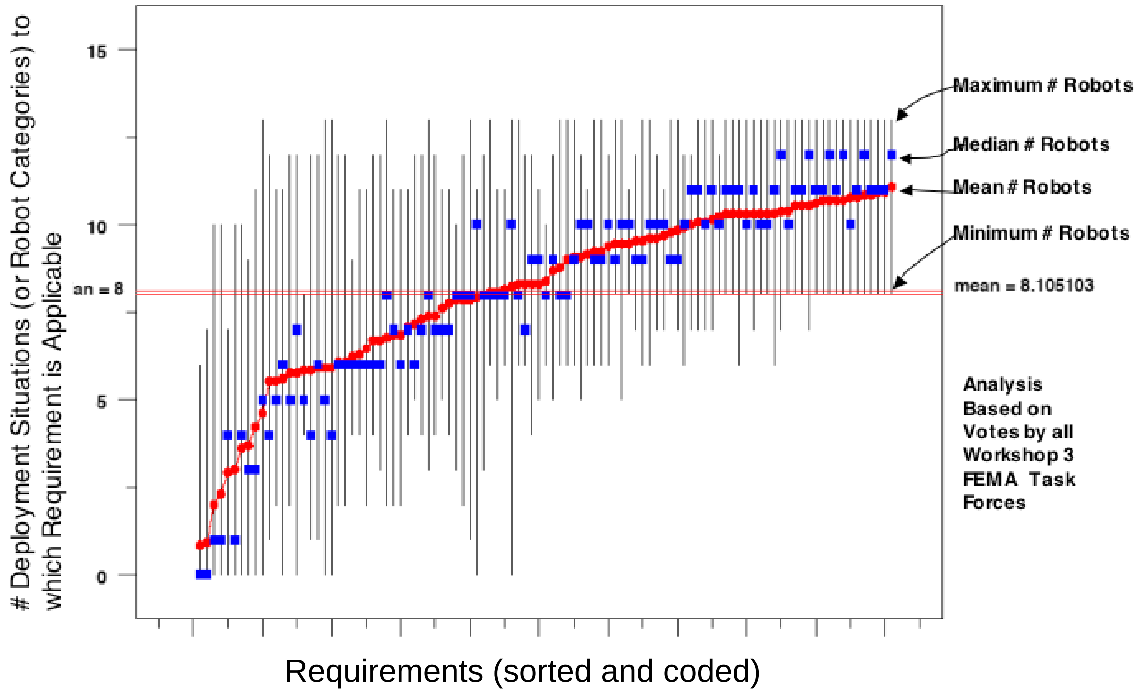


Figure 6: Analysis of Requirements Data. These plots show the four different parameters that were analyzed for the 103 requirements. The responders voted on the applicability of each requirement with respect to a robot/deployment category. For each requirement, the mean, median, minimum, and maximum score was computed. Score refers to the number of applicable robots/deployment categories for each requirement.



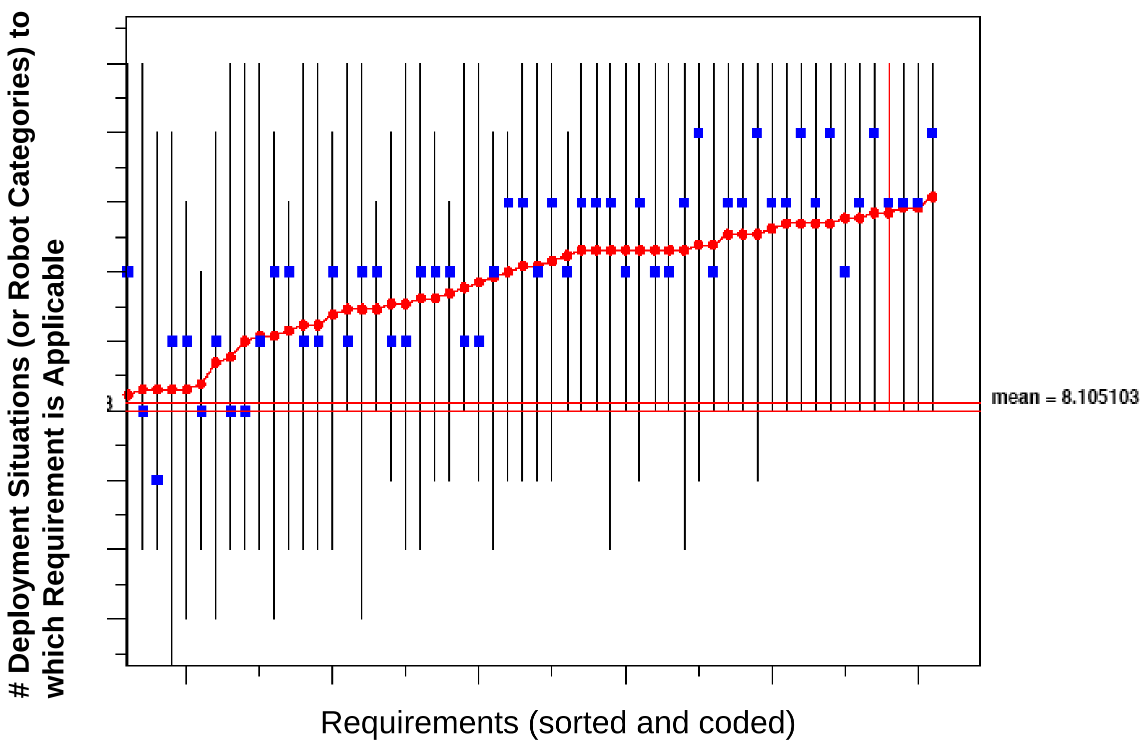


Figure 7: Combined measures of requirements' applicability to different types of robot/deployment categories. The top figure shows all 103 requirements ranked according to how well they meet the selection criteria; the bottom figure shows just the ones that best meet the criteria described in the text.

CANDIDATE WAVE 1 REQUIREMENTS

This chapter lists the candidate Wave 1 requirements for which the first set of standard test methods will be developed. These requirements are divided into two groups: Tier 1 is the set considered most widely applicable by the voting task forces. Several 2nd Tier requirements are included in the initial Wave 1 emphasis due to their similarity to 1st Tier requirements, allowing a single test for both. The Wave 1 requirements are considered to be minimum competences for US&R robots. They are necessary, but not sufficient, for ensuring that the robots are useful and usable in the challenging application of urban search and rescue.

Table 5: Candidate Wave 1 Requirements

(red) *	All 1st Tier requirements (21) are included and marked with an asterisk and highlighted with red
(yellow)	2nd Tier requirements (5), highlighted in yellow, are included due to their close connection with 1st Tier requirements, allowing inclusion in the same standard test methods.

Number:	**03**
Type:	**CHASSIS**
Sub-Type:	**ILLUMINATION**
Requirement:	**ADJUSTABLE**
Metric:	**YES/NO**
Description:	This requirement captures the responders' expectation to use video in confined spaces and for short-range object identification, which can wash out from excessive illumination of the scene.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**06 ***
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**RANGE – BEYOND LINE OF SIGHT**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to project remote situational awareness into compromised or collapsed structures or to convey other types of information. They specifically noted that the robot should be able to ingress a specified number of meters into the worst case collapse, which was further defined as a reinforced steel structure. This requirement also covers operations around corners of buildings and other locations beyond line of sight. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**07 ***
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**SECURITY**

Metric:	**SCALE 1-5** 1 = No security 3 = Command security only 5 = Both data and command security
Description:	This requirement captures the responders' expectation to use this system in sensitive public situations where maintaining control of remotes systems is imperative and limiting access to video images and other communications to authorized personnel is prudent. They added that the system should be shielded from jamming interference and encrypted for security, but made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**08**
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**RANGE – LINE OF SIGHT**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to project remote situational awareness or to convey other types of information down range within line of sight. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**11 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**N/A**
Requirement:	**INITIAL TRAINING**
Metric:	**HOURS**
Description:	This requirement captures the responders' expectation to minimize the initial training necessary to become proficient in operation of the system. This training should include supporting material sufficient for training in the specified period and culminate in certification.
Test Method:	**SEE ACCEPTABLE USABILTY TEST**

Number:	**12 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**N/A**
Requirement:	**PROFICIENCY EDUCATION**
Metric:	**HOURS ANNUALLY**
Description:	This requirement captures the responders' expectation to minimize the annual proficiency training necessary to maintain certification.
Test Method:	**SEE ACCEPTABLE USABILTY TEST**

Number:	**13 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**N/A**
Requirement:	**OPERATOR RATIO**
Metric:	**NUMBER OF OPERATORS PER ROBOT**
Description:	This requirement captures the responders' expectation to minimize the number of operators necessary to operate any given system and perform the associated tasks effectively.
Test Method:	**SEE ACCEPTABLE USABILTY TEST**

Number:	**14 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**N/A**
Requirement:	**ACCEPTABLE USABILITY**
Metric:	**EFFECTIVENESS (PERCENT); USER SATISFACTION (SCALE 1-5)**
Description:	This requirement captures the responders' expectation to operate any given system to perform the associated tasks effectively. The metric will measure the percent of timed tasks operators can successfully complete. This metric is discussed in greater detail in the Test Methods: Human-System Interaction section of this report.
Test Method:	**SEE ACCEPTABLE USABILTY TEST**

Number:	**26 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**CONTEXT**
Requirement:	**LIGHTING CONDITIONS**
Metric:	**SCALE 1-5** 1 = Complete darkness 3 = Daylight without direct glare 5 = Direct glare on interface
Description:	This requirement captures the responders' expectation to view and use the operator console in different lighting conditions. They noted that special emphasis should be placed on "no light" conditions and "direct glare" onto operator displays (from sunlight, helmet lights, etc.).
Test Method:	**SEE ACCEPTABLE USABLITY TEST**

Number:	**29**
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**CONTEXT**
Requirement:	**PROTECTIVE CLOTHING**
Metric:	**SCALE 1-5** 1 = No protection 3 = Minimum protection (threshold) 5 = Complete protection (objective)
Description:	This requirement captures the responders' expectation to be operating the system while wearing personal protective equipment such as gloves, helmet, eye protection, ear protection, etc. The operator should be able to maintain acceptable usability (discussed in greater detail in the Test Methods: Human-System Interaction section of this report) of the system while wearing the stated level of personal protective equipment
Test Method:	**SEE ACCEPTABLE USABILTY TEST**

Number:	**30 ***
Type:	**HUMAN-SYSTEM INTERACTION**
Sub-Type:	**DISPLAY**
Requirement:	**DASHBOARD**
Metric:	**YES/NO ; EFFECTIVENESS (PERCENT)**
Description:	This requirement captures the responders' expectation to monitor general system health and status (e.g. orientation, communication strength, power level, etc.). They identified two types of information: (A) Display of organic information: 1) system health status, i.e. power, motors, sensors, comms, etc.; 2) robot pose, i.e. absolute (x,y,z) or relative location from a start point; 3) constraints imposed by environment, i.e. inhibitors, manipulator problems, occluded or blocked sensors; (B) display of

external information: 1) Hazmat; 2) Temperature; 3) Other payload sensors. In addition to determining if the information is present, it is advisable to perform a series of empirical tests to determine if the operator(s) can accurately interpret the displayed information.	
Test Method:	**SEE DASHBOARD CHECKLIST; ACCEPTABLE USABILITY TEST**

Number:	**34 ***
Type:	**LOGISTICS**
Sub-Type:	**CACHE PACKAGING**
Requirement:	**WEIGHT**
Metric:	**KILOGRAMS PER CONTAINER**
Description:	This requirement captures the responders' expectation to move and store all equipment using existing methods and tools.
Test Method:	**TBD**

Number:	**35 ***
Type:	**LOGISTICS**
Sub-Type:	**N/A**
Requirement:	**MEAN TIME BEFORE FAILURE (MTBF)**
Metric:	**OPERATING HOURS**
Description:	This requirement captures the responders' expectation to use all equipment for the entire duration of a deployment (10 days maximum). Failure means major repairs of integrated components that need to be addressed by the manufacturer or other technical expert.
Test Method:	**TBD**

Number:	**36 ***
Type:	**LOGISTICS**
Sub-Type:	**CACHE PACKAGING**
Requirement:	**SETUP TIME**
Metric:	**MINUTES**
Description:	This requirement captures the responders' expectation to move, unpack, and assemble all equipment to a ready state using existing methods and tools. The setup time is from on-site delivery to operation.
Test Method:	**TBD**

Number:	**38 ***
Type:	**LOGISTICS**
Sub-Type:	**CACHE PACKAGING**
Requirement:	**VOLUME PER CONTAINER**
Metric:	**SCALE 1-5** 1 = Pelican 1650 box 3 = Hardigg box checkable on commercial aircraft 5 = Ropack model 4048, 4039 with drop door
Description:	This requirement captures the responders' expectation to move and store all equipment using existing methods and tools.
Test Method:	**TBD**

Number:	**39 ***
Type:	**LOGISTICS**

Sub-Type:	**FIELD MAINTENANCE**
Requirement:	**SPARES AND SUPPLIES**
Metric:	**PERCENT OF ROBOT WEIGHT**
Description:	This requirement captures the responders' expectation to be self-sustaining for 72 hours without re-supply from outside the base of operations. Field maintenance can be performed at the base of operations.
Test Method:	**TBD**

Number:	**40 ***
Type:	**LOGISTICS**
Sub-Type:	**FIELD MAINTENANCE**
Requirement:	**DURATION**
Metric:	**MINUTES**
Description:	This requirement captures the responders' expectation to minimize the amount of time required to perform routine maintenance operations in the field, potentially in-situ on a rubble pile or other awkward location.
Test Method:	**TBD**

Number:	**41 ***
Type:	**LOGISTICS**
Sub-Type:	**FIELD MAINTENANCE**
Requirement:	**TOOLS**
Metric:	**SCALE 1-5** 1 = Requires special tools 3 = Simple tools (e.g., screw driver) 5 = No tools required
Description:	This requirement captures the responders' expectation to minimize the need for specialized tools to perform field maintenance at the base of operations.
Test Method:	**TBD**

Number:	**42 ***
Type:	**LOGISTICS**
Sub-Type:	**FIELD MAINTENANCE**
Requirement:	**INTERVALS**
Metric:	**SCALE 1-5** 1 = 12 hours 3 = 24 hours 4 = 72 hours 5 = 10 days
Description:	This requirement captures the responders' expectation to minimize the mean time between required field maintenance performed at the base of operations.
Test Method:	**TBD**

Number:	**56 ***
Type:	**OPERATING ENVIRONMENT**
Sub-Type:	**N/A**
Requirement:	**WATER**

Metric:	**SCALE 1-4** 1 = Not water resistant 2 = Wash down 3 = Submersible 4 = Water resistant to 12 meters
Description:	This requirement captures the responders' expectation for the system to maintain operations in wet environments.
Test Method:	**TBD**

Number:	**67 ***
Type:	**POWER**
Sub-Type:	**N/A**
Requirement:	**WORKING TIME**
Metric:	**SCALE 1-5** 1 = 1 hour 3 = 4 hours 5 = 12 hours
Description:	This requirement captures the responders' expectation to maintain operations beyond basic mobility requirements within a given terrain type (see mobility requirements within terrain types). The system must have sufficient power to operate for the specified number of hours, assuming one power charge for one out and back mission.
Test Method:	**TBD**

Number:	**68 ***
Type:	**POWER**
Sub-Type:	**N/A**
Requirement:	**SUSTAINMENT**
Metric:	**SCALE 1-5** 1 = 12 hours 3 = 24 hours 4 = 72 hours 5 = 10 days
Description:	This requirement captures the responders' expectation to maintain operations in the field before re-supply of power is needed. The system must have sufficient power to operate for the specified number of hours/days before needing re-supply from the base of operations.
Test Method:	**TBD**

Number:	**69 ***
Type:	**POWER**
Sub-Type:	**N/A**
Requirement:	**RUNTIME INDICATOR**
Metric:	**YES/NO**
Description:	This requirement captures the responders' expectation to manage power resources to effectively plan mission durations, points of no return, and other important power considerations. The operator display must inform the operator of the remaining power level as a percentage of total runtime.
Test Method:	**TBD**

Number:	**96**

Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**SYSTEM ACUITY - NEAR**
Metric:	**MILLIMETERS**
Description:	This requirement captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and detailed inspection (hence the emphasis on short-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that this requirement is closely tied to the need for adjustable illumination to avoid washing out the image of close objects. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**99 ***
Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**SYSTEM ACUITY - FAR**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and path planning (hence the emphasis on long-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that the limiting case for long-range system acuity is probably assessment of structural integrity of buildings. This requires identifying and measuring cracks in walls, inspecting the tops/bottoms of load bearing columns, and generally assessing the squareness of walls, ceilings, and floors. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**101**
Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**FIELD OF VIEW**
Metric:	**DEGREES**
Description:	This requirement captures the responders' expectation to use real-time video for a variety of tasks. The responders noted that this requirement is closely tied to requirements addressing independent pan/tilt capabilities.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Chapter 4

TEST METHODS

The principal output of this program will be standard tests methods and metrics for the various performance requirements and characteristics defined by the responders. Test methods that are accepted by all interested parties: end users (responders), manufacturers, developers, and standards organizations will ensure that there are reproducible, meaningful evaluations of how to measure the performance and characteristics of robots. The iterative review process of the requirements, metrics, and testing methods is designed to produce measurements of capabilities that are pre-requisites to fieldable robots. The test methods should be objective, clearly defined, and reproducible by any developer to support tangible goals for system capabilities. This set of rigorous test methods will enable robot and component developers to exercise their systems in their own locations in order to attain the required performance. The standard tests will be hosted by certified sites, each hosting a particular set of tests to avoid issues regarding correlation of tests conducted at parallel sites.

A test method will be developed for each of the performance requirements listed in Chapter 3. The test methods will be designed by NIST, in consultation with responders, developers, and technical experts. In this section, we provide some details on possible performance tests. The first example can be designed and executed so as to evaluate multiple performance requirements simultaneously. The sections that follow provide more details on the Human-System Interaction aspects, which form a large percentage of the Wave 1 requirements.

EXAMPLE TEST METHOD: REAL-TIME VISION SYSTEM ACUITY

This example test method (Figure 8) and associated results reporting sheet (Figure 9) show one way to test the performance of the robot's vision system. The test could address requirements listed in Table 6 from the 1st and 2nd Tier. The test outlined is a timed test to read the eye-charts T1, T2 then T3 in sequence from a variety of distances and robot orientations to measure the operator's ability to remotely direct and re-direct perception. Charts T1 and T2 in the far field represent the top and bottom of a load bearing column, for example, identified by structural engineers as of particular interest in the far field (note: structural engineers will likely provide the stressing cases for visual acuity requirements). The test includes data captures from a variety of distances from the far field charts to determine the system's maximum acuity; several robot orientations to differentiate articulated pan/tilt systems from fixed cameras; and far to near focus changes that also require variable illumination when tested in the dark. The test would also be conducted using both wired and wireless communication modes (radio noise can devastate image resolution). The goal of this test method is to isolate easy to measure metrics: time to perform all three readings and average acuity across a variety of relevant situations. This allows direct comparison of performance capabilities without necessarily stating what level of performance is acceptable for a given implementation, user, or role.

Table 6: Requirements Addressed by Example Test Method

3. Chassis	Illumination	Adjustable
6. Communications		Range: Beyond Line of Sight
7. Communications		Security
8. Communications		Range: Line of Sight
96. Sensing	Real-Time Video	Real time remote video system (near)
99. Sensing	Real-Time Video	Real time remote video system (far)
101. Sensing	Real-Time Video	Field of View

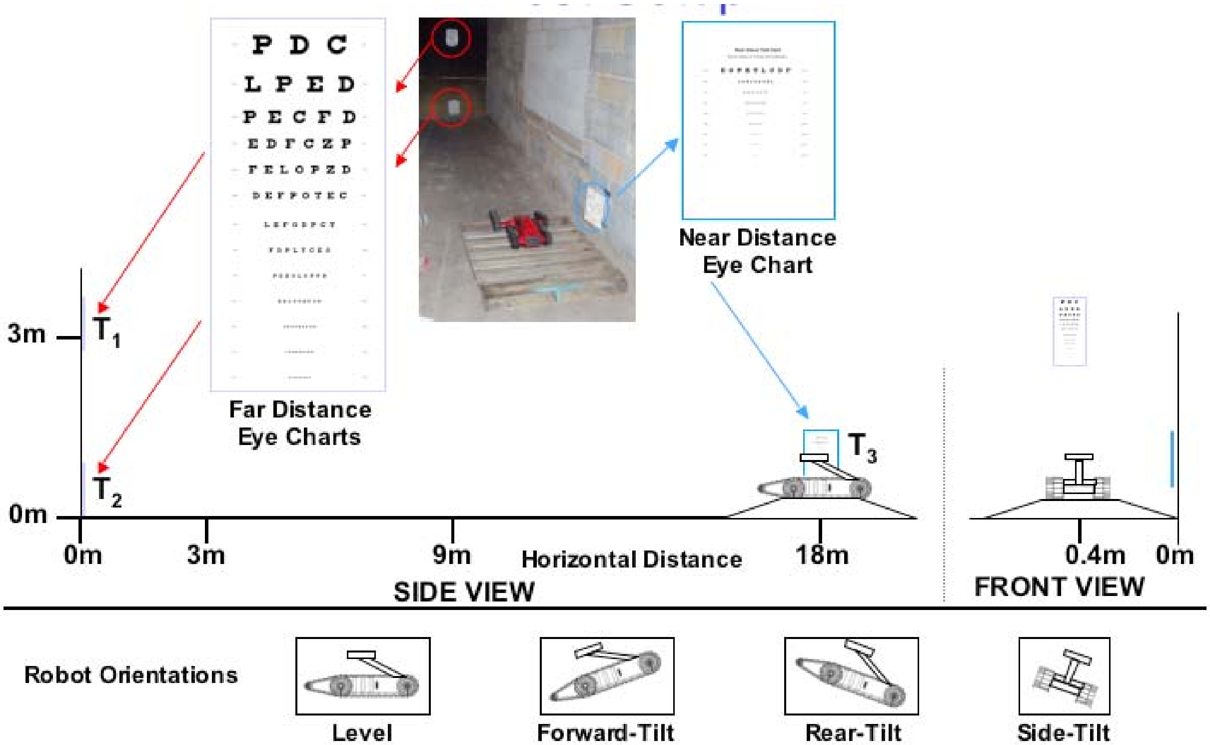


Figure 8: Set Up for Test

SYSTEM VIDEO RESOLUTION TESTING

Communication Mode (Circle One)

Tethered Wireless

DATE:
TEST LOCATION:
TEST LEADER:
OPERATOR:
ROBOT:

Horizontal Distance	Orientation	Lights On				Lights Off			
		T1 Acuity	T2 Acuity	T3 Acuity	Time	T1 Acuity	T2 Acuity	T3 Acuity	Time
18m		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
9m		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
3m		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
NOTES:									

Figure 9: Test Results Report Sheet

TEST METHODS FOR HUMAN-SYSTEMS INTERACTION REQUIREMENTS

For the first wave of requirements there are basically two types of human-systems interaction requirements: those that must be empirically validated in user testing, and those that can be verified using a simple checklist. In addition, several of the human-system interaction requirements can be considered as conditions that must be included in the empirical tests. Table 7 below lists the candidate requirements for wave 1 and specifies the type of evaluation for each. A more complete discussion of each follows.

Table 7: Human-System Interaction Requirements Evaluation Types

Human- Systems Interaction Requirement	**Type of evaluation**	**Comment**
11. Initial training	Check list User testing Evaluation Condition	We can check that initial training is provided but the adequacy of training should be established empirically. Acceptable usability should be initially evaluated after operators have been given the specified amount of training.
12. Proficiency education	Check list User testing Evaluation Condition	Proficiency education can also be checked for existence but the effectiveness should also be evaluated. Periodically, operators should be given additional training and should then be retested to ascertain if they achieve acceptable usability with the robot.
13. Operator ratio	User testing	The acceptable usability evaluations should be conducted initially with the specified number of operators. The specified number of operators/robot should be a design criterion for developers
14. Acceptable usability	User testing	Operators of the correct demographics who have had the required amount of training will be given a set of tasks to perform with the robot. The efficiency, effectiveness, and user satisfaction of each task will be assessed.
30. Dashboard	Check list User testing	The information requirements specified can be checked for presence in the UI. However, the presentation of those elements will influence the acceptable usability performance. Therefore it is recommended that empirical evaluations be performed to test the accuracy of interpretations by operator(s).

EXAMPLE TEST METHOD: ACCEPTABLE USABILITY

Acceptable Usability evaluations can be used to test all five human-system interaction requirements for Wave 1. Acceptable usability evaluations will use the Common Industry Reporting Format (CIF), ANSI NCITS 354-2001 standard. The CIF can be written as a requirement and each vendor can use the CIF to document the acceptable usability evaluations that have been done.

The CIF specifies the number of users, the demographics of the users (which will include the amount of training the users have been given), the tasks that have been tested, and the various contexts that have been used for evaluation. The results of the evaluation are summarized as:

- Effectiveness (the number of tasks each user was able to perform without help)
- Efficiency (the time for the user to perform tasks)
- User satisfaction (users' ratings according to a standardized satisfaction questionnaire)

Specifications for acceptable usability evaluation for DHS US&R would include the following contexts:

Users: while the overall number of subjects should be significant (8 or greater), the evaluation should be conducted using the specified ratio of operators to robots. If the ratio desired is 1 operator for 1 robot, then all tasks should be tested using only 1 operator. If the ratio desired is 2 operators for 1 robot, then 8 pairs of operators should be used in the evaluation.

Initial Training: In addition, the operators should be initially given the specified amount of training. Additional demographics will be supplied as the requirements for these are elicited.

Proficiency Education: Operators should also be given the desired annual training and then tested to ensure that they can perform the specified tasks with the prescribed acceptable usability measures.

Context: Lighting and protective clothing become contexts in which the various tasks should be tested. For each task defined, the tests should be performed in the three lighting conditions: no light; direct light without glare; and direct glare on interface. All operators should wear the specified protective clothing (none, minimum, or full protective gear) during tests.

Tasks: TBD. The specific tasks for the various scenarios and the types of robots used will need to be defined by the responders and developers.

Metrics: TBD. The CIF specifies effectiveness, efficiency, and user satisfaction. We suggest that for the robot tasks, effectiveness measures be redefined as consisting of several components: accuracy, collisions with avoidable obstacles, and collisions with unavoidable obstacles. The weights of these different components will vary depending on the primitive task. For example, the task of navigating the robot to a certain point in a subsurface void, the accuracy would be determined by how close to the desired location the operator was able to navigate the robot. The number of collisions with objects will be recorded, as will the number of times the robot becomes incapacitated. If the task involves navigation between uncollapsed buildings, the number of collisions may become less important. However, if the task involves navigation within a collapsed building, the collisions could become extremely important. Efficiency, or time to complete the task, is of interest in both cases. However, it is important for us to know whether the time for the task was because the robot was stuck on obstacles while navigating or whether the operator was navigating extremely slowly due to limited remote situational awareness.

In addition, collecting the operator's perceived workload using the NASA Task Load Index (TLX) for each task tested is very important [7]. In operational scenarios, the operators will be required to perform other ongoing tasks, such as communicating with various specialists on the team, and as the operating conditions will be extremely stressful, it is important the human-robot interaction not produce an excessive workload.

While much refinement is needed specify tasks and measures, the following is an example of our approach:

1. Navigating to a specific point or location in all terrains
    a. Workload (NASA TLX)
    b. Time
    c. Number of Collisions
    d. Number of times got stuck
    e. Success – how close to the point of location
2. Reporting locations
    a. Workload (NASA TLX)
    b. Accuracy
3. Tracking coverage
    a. Workload (NASA TLX)
    b. Accuracy
4. Operating sensors (cameras, hazmat, etc.)
    a. Workload (NASA TLX)
    b. Time
    c. Effectiveness
5. Recognizing robot health (dashboard)
    a. Workload (NASA TLX)
    b. Time
    c. Accuracy

EXAMPLE TEST METHOD: CHECKLISTS

Some responder requirements will be easier to measure than others. The responders defined several requirements with "yes/no" metrics based on expectations of inclusion within the overall system (i.e. *#03 Chassis : Illumination : Adjustable)*. They also defined metrics based on conformity to specific operational requirements (i.e. *#38 Logistics : Cache Packaging : Volume per Container*), which are tied to numeric scales with model numbers of shipping containers, for example. Both of these types of requirements can be verified with a simple checklist. The responders also defined slightly more complicated checklist metrics for requirements such as *#29 Human-System Interaction : Display : Dashboard* as part of the operator control unit, although this requirement did not rise to the top level of consensus requirements targeted for Wave 1. For this type of requirement, a checklist can still be used to determine if the required information is present in the operator control unit. For example, this checklist will include items such as:

1. System health status: power remaining, motors, sensors, communications, etc.
2. Robot pose: absolute measures or relative measures from the starting point
3. Display of external information: temperature, hazmat information, other payload sensors

Final checklists of this sort will be compiled based on more detailed discussions of the specific requirements. Meanwhile, several acceptable usability tasks will also be defined to determine if the presentation of this information is easily accessible by the operator (s).

Chapter 5

NEXT STEPS

DEVELOPMENT AND STANDARDIZATION OF TEST METHODS

The proposed Wave 1 requirements will be further detailed after receiving input at the initial public forum (held May 13th, 2005 at NIST). In fiscal year 2005, either a single standards development organization (SDO) or a joint SDO team will be identified to host the US&R robot performance standards. The Wave 1 requirements will have corresponding testing methods developed in the coming year. The human-system interaction requirements team will conduct regional workshops with technical search specialists who have been designated as likely candidates for operating the robots. These workshops will be used to develop the primitive tasks to be used in the acceptable usability test method. The remainder of the requirements will have accompanying test methods by the end of the program.

The set of requirements will also be examined to determine if other requirements for performance and human-system interaction have been covered (Drury et al [5], and The Center for Robot Assisted Rescue [6]). Any additional guidelines will be considered for inclusion in the next wave. In addition, as responders consider the possible concepts of operations that will be used with robot assisted search and rescue, additional human-system interaction requirements may emerge.

As indicated in the timeline diagram (Figure 2), this program will take an iterative development approach to ensure that the performance requirements are appropriate and that the vendor and technology communities are able to interact with the end users on a frequent basis. These events will also present opportunities to dry-run testing protocols to an audience of responders and technologists. Comments from these communities can help refine and strengthen the tests. The events will also serve to provide feedback on a frequent basis to the technology developers, who will be able to see how their systems perform against the emerging performance standards. Events similar in flavor have been held by other organizations, such as the National Aeronautics and Space Administration's Disaster Assistance and Rescue Team (NASA DART) and the Center for Robot-Assisted Search and Rescue. For instance, in May 2004, NASA DART organized a "Technologist meets Responders" workshop at their Collapsed Structure Rescue Training Facility. At this workshop, responders had the opportunity to exercise various new technologies relevant to search and rescue, including robots. In the evaluations by responders, robotic devices were considered at best a 3 (out of 10) in overall utility during emergency response, except in certain specialized cases, however the potential utility was considered to be "very high" (probably a 10). However, they stated that much work is needed, particularly in the areas of mobility (traversing difficult terrain), maintaining communications and power links, and improving the usability of human interfaces [16].

The first of these events under this standardization program is being planned for August 2005, possibly in conjunction with a FEMA Task Force Leader's meeting. Candidate test methods for a subset of the Wave 1 requirements will be demonstrated and evaluated. Vendors and technologists are encouraged to bring their robots or components to demonstrate and to run through the prototype tests. In February 2006, a workshop will be held in conjunction with the American Nuclear Society International Joint Topical Meeting: Sharing Solutions for Emergencies and Hazardous Environments (http://www.2006sharingsolutions.com/workshopD.shtml). This workshop will provide opportunities to share progress in the standard test methods development process and exchange ideas amongst the stakeholder communities. In August 2006, a joint Performance Metrics for Intelligent Systems and IEEE Safety, Security, and Rescue Robotics conference will be held at NIST. This will be another opportunity for evaluation of test methods and robots by vendors, technologists, responders, and standards committee members.

The somewhat informal tests that will occur on a regular basis in the early part of the program will be expanded into technology readiness level evaluation exercises. As the technologies comprising the US&R robotic systems evolve, it will be possible to conduct more rigorous tests under realistic scenario-driven exercises involving responders. These tests will expose any gaps in the existing performance requirements and testing protocols and help refine existing requirements and tests prior to submitting them to the standards process.

Technology Readiness Levels (TRLs) are a systematic metric and associated measurement system that supports both the assessment of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. First developed by NASA [3], this 9-level scale defines broad categories of deployment readiness of technologies, components, subsystems, or systems. The Department of Defense has been using TRL terminology and methodology for various programs. Their version of the scale is shown in Table 8. DHS will work with NIST to devise TRL assessment exercises for US&R robots in order to measure the maturity of component technologies (such as particular sensors) as well as overall robotic systems. TRL assessment exercises will provide essential evaluations of performance for US&R robots, providing statistically significant performance data for developmental and fielded systems. NIST is at the forefront of TRL evaluation of robotic systems, having designed and administered TRL exercises for the Army Research Laboratory to evaluate the maturity of the autonomous navigation system for the Demo III eXperimental Unmanned Vehicle (XUV), an unmanned scout vehicle[4]. For this assessment, NIST conducted 650 discrete missions, covering over 500 km of autonomous driving in arid, vegetated, and urban terrains. NIST plans to leverage this experience and apply relevant techniques and methods to US&R robot evaluations.

In the coming years, one or more testing and evaluation sites will be selected and certified by NIST as being able to carry out the test methods developed within this program. The test site(s) will conduct any official testing and evaluation of robots for urban search and rescue.

Additional efforts will support and complement development of standard test methods for robots. These efforts involve classification of the robot capabilities, along with classification of buildings, collapses, and disaster types. Since robotics itself is a multidisciplinary and evolving field, classifications serve to organize the knowledge about the technologies involved. A classification approach to the types of buildings and collapses may help develop guidelines for the application of robotic technologies to particular situations. More information on the robot and building/collapse classifications can be found in Chapters 6 and 7. A compendium of robot capabilities is also being developed by a third party. The compendium will list vendor-provided specifications in addition to the certified performance results captured using the standard test methods developed under this program.

Table 8 - Technology Readiness Level Descriptions

1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins with to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic	Active research and development is initiated. This includes analytical studies and laboratory studies to

	physically validate analytical predictions of separate elements of the technology. Examples include components not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in a operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and 'flight qualified' through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specs.
9. Actual system 'flight proven' through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Chapter 6

ROBOT AND CAPABILITIES CLASSIFICATION

Given the new and evolving nature of robotics applied to challenging environments such as collapsed buildings, a means of organizing knowledge about the diverse population of robots and their components and capabilities may help users and developers better understand what is available and where there are gaps. To this end, this program encompasses efforts that will create classification structures (taxonomies) for robots and their capabilities, as well as for buildings and collapse or disaster types. The building classification work is described in Chapter 7. The robot capabilities classification is being addressed through the use of ontologies. Whereas the robot and capabilities classification effort will be defining the data structures to capture the pertinent characteristics of robots, a complementary effort described in Chapter 8, will populate these structures with data about robots which are currently available. This data will not only include the physical characteristics of the robots, but will also include the results of standard performance test. This "compendium" will be available in database format.

The goal of this Robot Ontology effort is to develop, and begin to populate, a neutral knowledge representation (the data structures) capturing relevant information about robots and their capabilities to assist in the development, testing, and certification of effective technologies for sensing, mobility, navigation, planning, integration and operator interaction within search and rescue robot systems. This knowledge representation must be flexible enough to adapt as the robot requirements evolve. As such, we have chosen to use an ontological approach to representing these requirements.

In this context, an ontology can be thought of as a knowledge representation approach that represents key concepts, their properties, their relationships, and their rules and constraints. Whereas taxonomies usually provide only a set of vocabulary and a single type of relationship between terms (usually a parent/child type of relationship), an ontology provides a much richer set of relationship and allows for constraints and rules to govern those relationships. In general, ontologies make all pertinent knowledge about a domain explicit and are represented in a computer-interpretable fashion that allows software to reason over that knowledge to infer addition information.

By taking an ontological approach, we provide for:

- Less ambiguity in term usage and understanding
- Explicit representation of all knowledge, without hidden assumptions
- Conformance to commonly-used standards
- Availability of the knowledge source to other arenas outside of urban search and rescue
- Availability of a wide variety of tools (reasoning engines, consistency checkers, etc.)

The benefits of having a robot ontology are numerous. In addition to providing the data structures to represent the robot requirements, the robot ontology can allow for:

- The selection of equipment and agents for rescue operations
- Assistance in the exchange of information across US&R teams
- The ability to find the available resources that address a need
- The identification of gaps in functionality that can drive research efforts

The Robot Ontology is based on a number of existing technologies. They are:

- OWL (Web Ontology Language) – OWL is a World Wide Web Consortium (W3C) recommendation (as of February 10, 2004). It defines terms commonly used in creating a model of an object or process, including classes/subclasses, properties/subproperties, property restrictions, and instances. [11]

- OWL-S (Web Ontology Language – Services) – OWL-S is an OWL-based web service ontology, which describes the properties and capabilities of services in an unambiguous, computer-interpretable form. It was developed by the DARPA Agent Markup Language (DAML) Program. OWL-S is an upper ontology intended to be extended to meet specific applications. [14]
- Protégé – Protégé is an open source ontology editor developed at Stanford University. It supports class and property definitions and relationships, property restrictions, instance generation, and queries. Protégé accommodates plug-ins, which are actively being developed for areas such as visualization and reasoning. [13]

In addition, a number of existing knowledge representations have been found through a literature survey that will be / have been leveraged in the development of the Robot Ontology. These include:

- Efforts to determine the information requirements for a US&R ontology performed at the University of Electro-Communications in Tokyo, Japan [10]
- Efforts to develop a Mobile Robot Knowledge Base at SPAWAR [12]
- Efforts at the Center for Robot Assisted Search and Rescue (CRASAR) in the development of taxonomies for robot failures [9] and issues pertaining to social interactions between robots and humans [8]

An initial structure for the Robot Ontology has been developed. This initial structure can be broken down into the follow primary categories of knowledge:

- Structural Characteristics – describes the physical and structural aspects of a robot
- Functional Capabilities – describes the behavioral features of the robot
- Operational Considerations – describes the interactions of the robot with the human and the interoperability with other robots

Examples of knowledge captured in the structural characteristics category include (but are not limited to):

- Size
- Weight
- Tethering
- Power Source
- Locomotion Mechanism (wheeled, walking, crawling, jumping, flying, etc.)
- Sensors (e.g., camera, FLIR, LADAR, SONAR, GPS, Audio, Temperature Sensor)
- Processors

Examples of knowledge captured in the functional capabilities category include (but are not limited to):

- Locomotion Capabilities (e.g., max. speed, max. step climbing, max. slope climbing, etc.)
- Sensory Capabilities (e.g., min. visibility level, map building capability, self-localization, system health, etc.)
- Operational Capabilities (e.g., working time, setup time, max. force available to push, MTBF, MTBM, required tools for maintenance, run time indicator, sustainment (spares and supplies), etc.)
- Weather Resistance (e.g., max. operating temp, max. submergability level, etc.)
- Degree of Autonomy (e.g., joint level dependency, drive level dependency, navigation level dependency, etc.)
- Rubble Compatibility (e.g., ability to historically operate well in certain terrains)
- Communications (e.g., communication media, communication channel frequency, content standards, information content, communication locking, communication encryption)

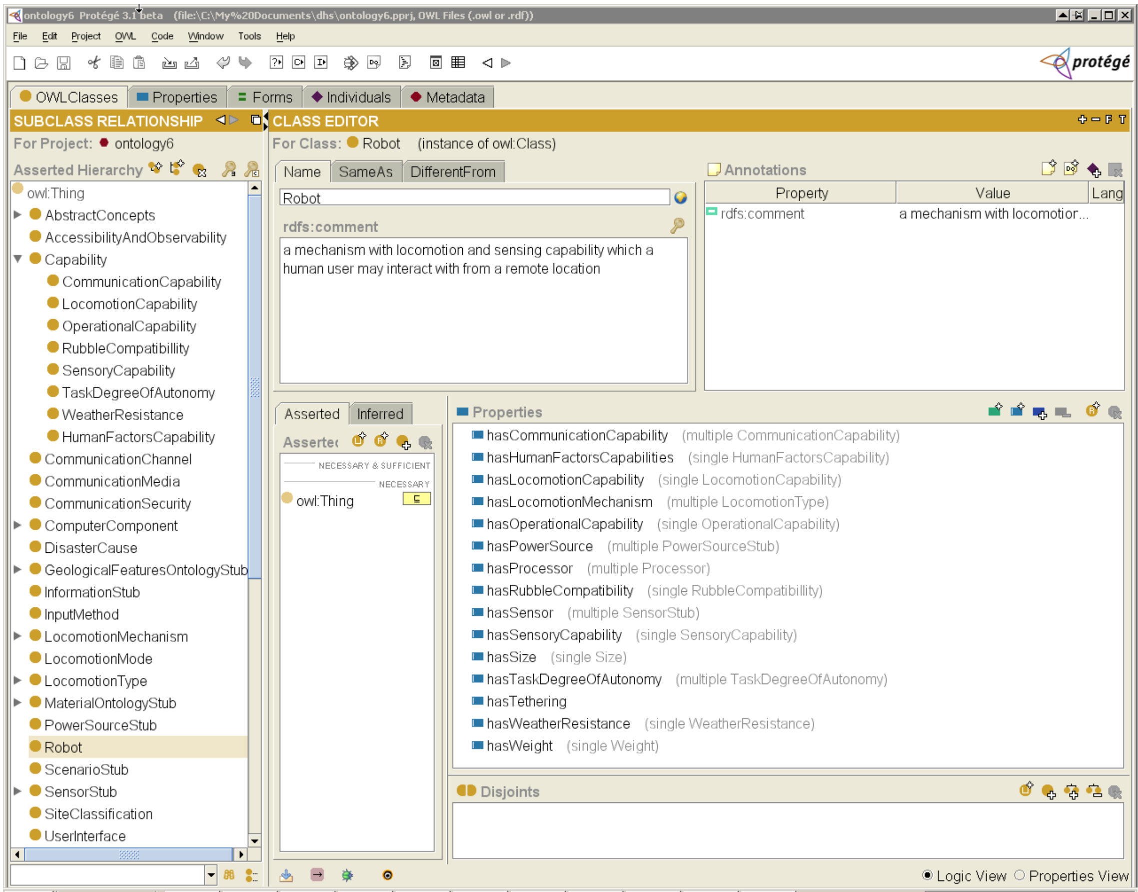


Figure 10: The Robot Ontology

Examples of knowledge captured in the operational considerations category include (but are not limited to):

- Human-System Interaction (operator ratio, initial training, proficiency education, acceptable usability, auto-notification, display type, packaging size)
- Intra-Group Interaction (i.e., interaction with other similar robots)
- Inter-Group Interaction (i.e., interaction with other 3rd party robots or computers)

Based on the technologies described earlier and based on the categories and requirements discussed above, we have developed an initial version of a Robot Ontology. Figure 10 shows a screenshots of the ontology (represented in Protégé) with associated explanation.

The column on the left shows the classes that are represented in the ontology. The box on the right (with the blue boxes on left) shows the attributes that are associated with the highlighted class (Robot). In the ontology, the robot is the highest-level concept. A mobile robot is defined as a mechanism with locomotion and sensing capability which a human user may interact with from a remote location. These robots have attributes such as hasCommunication Capability, hasHumanFactorsCapabilities, hasLocomotionCapabilities, etc. Each one of these attributes point to classes with more specific information. As an example, Figure 11 shows a screenshot of the attributes associated with hasOperationalCapabilities.

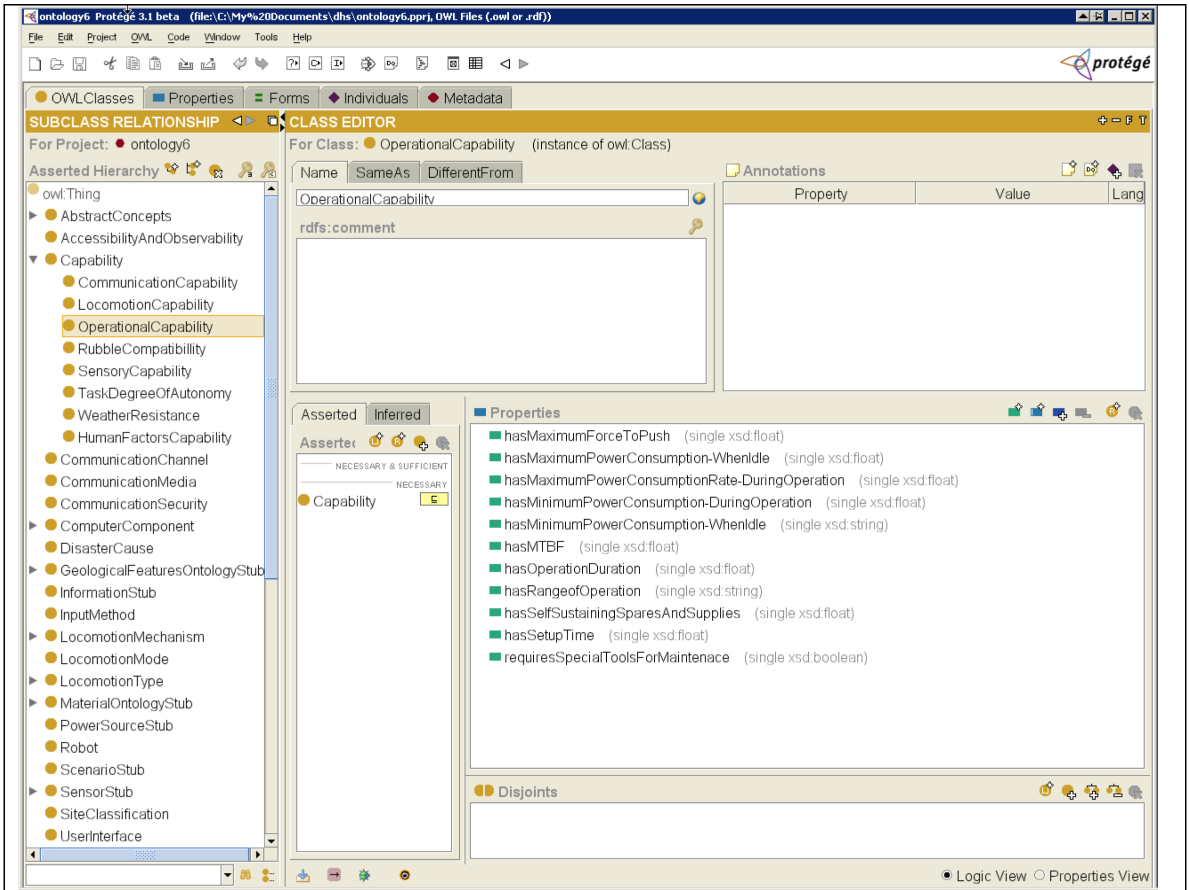


Figure 11: Operational Capability Attributes

To date, the Robot Ontology contains 230 classes, 245 attributes (properties), and 180 instances. As the project progresses, it is expected that the ontology will grow considerably.

Future work will focus on:

- Continue to specialize the robot ontology structure to provide greater level of detail
- Explore other standards efforts and existing ontologies that can be leveraged
    - Sensors
    - Power Source
    - Materials
    - Environment
- Continue to incorporate the requirements from the requirements workshops into the robot ontology structure
- Explore the use of reasoning engines to suggest robots for different situations
- As requirements for the building and collapse types become available, start building a building and collapse type ontology.

Chapter 7

BUILDING AND COLLAPSE TYPES

As an integral effort to define test methods for urban search and rescue robotics, a description and classification of potential operating environments is required. To that end, the Building and Fire Research Laboratory (BFRL) at NIST will be developing a structural collapse taxonomy (an orderly classification). The 2005 calendar year effort will focus on developing a framework for integrating building classification, disaster type, and collapse type to provide general descriptions of probable operating environments.

Existing sources of building classifications and how they relate to collapse, such as the ASCE/FEMA 310 – Handbook for the Seismic Evaluation of Buildings (Pre-standard) are being studied [15]. The publication defines 15 base model building types with subcategories resulting in 23 separate building descriptions, which could serve as a baseline for the collapse/disaster type taxonomy. Discussions are being held with participants from the National Construction Safety Team (NCST) to discuss building classifications and collapse categories. Information reviewed during assessments of building collapses by NCST includes Type of Construction (e.g., wood, masonry, steel, concrete), Type of Structure (e.g., moment frame), Height, and Type of Collapse (e.g., partial, total, progressive).

Initial discussions with responders regarding collapse categories yielded additional information. For their purposes (victim identification and recovery) the use of the structure and time of day (i.e. school / night) were more important data than specific construction types.

Experiments using laser scanning and range image analysis will also be performed to characterize rubble type. The first site to be analyzed will be the rubble pile at the Montgomery County MD Fire Rescue Training Academy. Figures 12, 13, and 14 show images of the rubble at the site, as well as preliminary data collection using a high-resolution, three-dimensional scanner. This work is initially being done on the exterior of rubble piles, but will be extended to interior void characterization where possible.

Figure 12: Montgomery County Fire Rescue Training Facility Rubble Pile

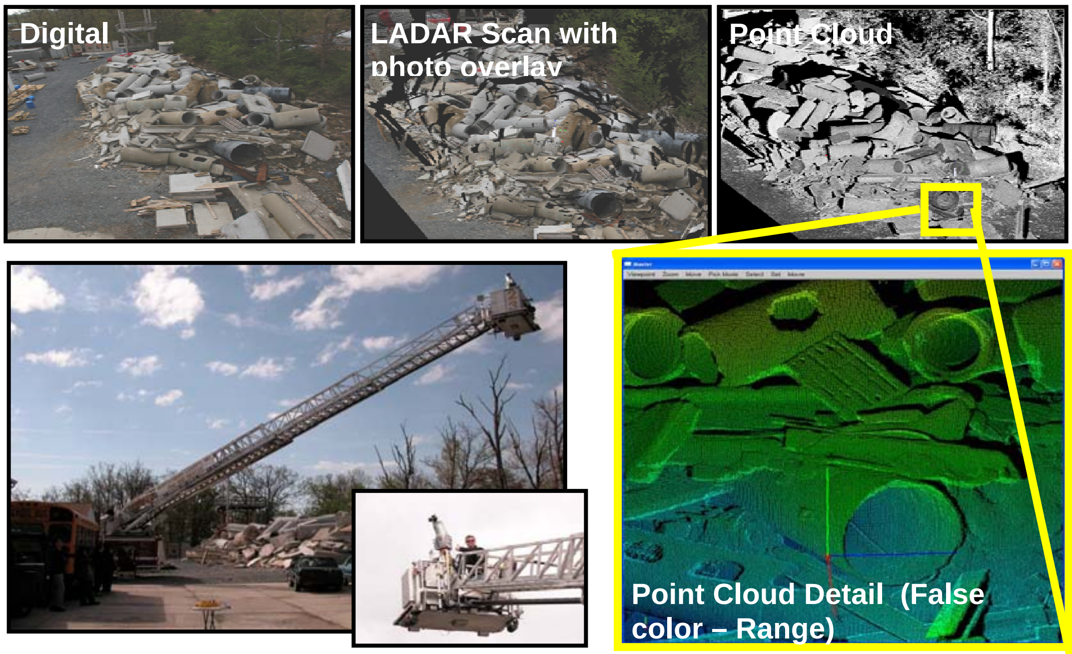


Figure 13: Data Collection Process. **This set of images show the overhead views of the rubble pile, the data capture rig, and a resulting point cloud captured by the three-dimensional scanner.**

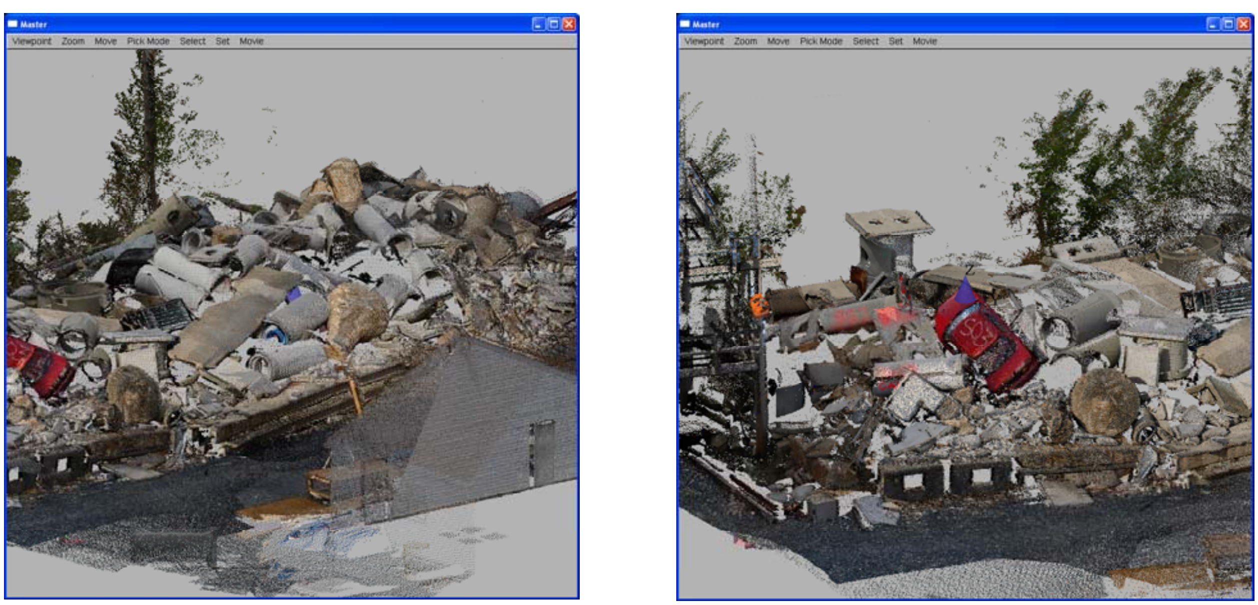


Figure 14: Multiple 3D Scans Registered Together. **These two images were produced by registering multiple point clouds collected around the rubble pile**

Chapter 8

COMPENDIUM OF ROBOT CAPABILITIES

Perhaps the most compelling advantage to be exploited by the application of mobile robot technologies to the US&R response challenge lies in their inherent freedom of design. While the rigors of military combat and typical Department of Defense (DoD) operating environments tend to focus requirements and military prototype designs into a relatively narrow field of candidates, the wide-ranging nature of DHS responsibility dictates otherwise.

Consider the case of a highly capable reconnaissance robot that loudly announces its location with a significant audio/visual or electro-magnetic (EM) signature, and is so light-skinned that a BB gun or .22 caliber bullet would put it out of action immediately. In spite of its superior mobility, sensing, or manipulative potential, it will probably fall far below a tactical military procurement cut line because its logistical burden and employment disadvantages far outweigh its operational value as a reconnaissance asset.

Domestic response organizations, however, do not share the military's need to maintain a stealthy, bullet-proof profile. In fact many of them may try to actually advertise their location and attract attention as a means promote face-to-face coordination and more effective communication between first responders and other emergency support entities. Thus the typically restrictive performance features that are viewed as detriments for defense applications may actually be perceived as operational *advantages* for domestic response purposes.

In considering the utility of mobile robots to support assessment and mitigation activities associated with both natural disaster and man made crises, it is clear that a much wider variety of environmental conditions and employment roles exists for response robots than for their military cousins. Consequently the set of design requirements for response robots will need to be significantly relaxed in value and expanded in type if we are to effectively exploit mechanical design freedom and extract maximum potential from this exciting technology area.

As requirements are relaxed, innovation and creative thought can be increased to address the expanded set of challenges associated with extreme conditions and adaptive tasks required of response robots operating in unstructured and dynamically shifting scenarios. In fact, a plethora of mobile robot prototypes have recently emerged from the aftermath of 09/11, presenting a wide range of response to both the government and commercial sector outside the DoD. (see Figure 15)

Figure 15: Collage of Potential Response Robot Candidates

It should be noted that while the focus of this effort remains oriented on the urban environment, this focus is not intended to be exclusionary – especially since the role of FEMA's US&R task force program is expected to continue to evolve as they are increasingly called upon to support a broad range of emergent missions with a more rural flavor as seen during the search for Challenger astronaut remains, the 2004 hurricane season, etc.

In recognition of this evolutionary nature, and the corresponding expansion in mobile robot platforms with response potential, NIST, under funding from the DHS S&T Directorate, has commissioned Blitz Solutions Inc. (BSI) to establish a Compendium of Response Robotics (CoRR). This database product will serve as an impartial, comprehensive shopping list and reporting mechanism by which both government and commercial response entities can analyze the return on investment associated with purchasing and/or leasing robotic platform(s) for application to any particular role or task that they have in mind.

The first generation of the CoRR will include basic characteristics (dimensions, weight, shape, etc.) and un-validated performance data (speed, duration, sensor resolution, etc.) claimed by each robot supplier. (See Figure 16 for an unverified example of what a page from the CoRR might look like. ***NOTE: THIS DATA IS FOR EXAMPLE ONLY! IT DOES NOT REFLECT ACTUAL DATA OR EVALUATION STATUS!***

The second generation CoRR will incorporate candidate and eventual standard test results conducted and validated by certified test sites. The goal is a Consumers' Report concept of actual performance based on similar test methods. The third and subsequent generations of the CoRR will implement a number of improvement and extensions commensurate with the evolution of the response robotics field.

Aurora

Automatika, Inc.
137 Delta Dr.
Pittsburgh, PA 15238
412.968.1022
www.automatika.com

EXAMPLE ONLY!
THIS DOES NOT REFLECT ACTUAL DATA OR EVALUATION STATUS!

Model:	Aurora	**Speed:**	max 1.6 m/sec
Manufacturer:	Automatika	**Locomotion:**	Steerable mono-tread
Common Name(s):	"caterpillar", "worm"	**Power:**	Li-ion rechargeable battery pack
Produced:	Prototype (2002)	**Battery Life:**	4-8 hrs
		Computing:	PC-104, Intel P3
Length	24"	**Communication:**	Wireless RS144/e-net
Width	6"	**Cameras:**	2 front & 2 rear
Height	4"	**Sensors:**	video, audio, pitch, roll, heading
Base Weight	20 lbs	**OCU:**	Mini console
Waterproof:	Submersible	**Behaviors:**	Self-righting
Options:	semi-autonomous operation, 2 additional bays and expansion ports, top mounted "cargo bed" for marsupial deployment		

EXAMPLE ONLY! THIS DOES NOT REFLECT ACTUAL DATA OR EVALUATION STATUS!
NOTES: While currently existing only as a prototype, the Aurora demonstrates confined space climbing ability and a sealed enclosure. However, as with many of the platforms in this class, this variant's inability to carry substantial cargo or deploy a manipulator currently limits the Aurora to primarily exploratory and sensor-emplacement roles. With wireless control, invertible operations, and extremely compact size, the Aurora is intended for confined space exploration and refuge detection but would benefit from the addition of more powerful lights.

Figure 16: Example of Compendium Entry

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APPENDIX A – REQUIREMENTS DEFINITION WORKSHOP PARTICIPANTS

Organization	Attended Workshop I	Attended Workshop II	Attended Workshop III
AZ-TF1	Lloyd Randall	Lloyd Randall	
CA-TF1	Tom Haus	Tom Haus	Tom Haus
CA-TF2	Rory Rehbeck	Rory Rehbeck	
	Bill Monahan	Bill Monahan	Bill Monahan
CA-TF3	Harold Schapelhouman	Harold Schapelhouman	
	Roger Miller	Roger Miller	Roger Miller
CA-TF6	David Lesh	David Lesh	
CA-TF7	Ford Davies		
CA-TF8	Richard Leap	Richard Leap	Richard Leap
IN-TF1	Sam Stover		Sam Stover
MA-TF1	Bradford Stocks		
	Bruce Naslund	Bruce Naslund	Bruce Naslund
		Alan Fisher*	
MD-TF1	Michael Steed	Michael Steed	Michael Steed
MO-TF1		Lee Turner	
NE-TF1	Michael Conditt	Michael Conditt	Michael Conditt
		Vance Behrens	
NY-TF1	George Hough	George Hough	George Hough
	Randy Miller	Randy Miller	
OH-TF1	Kevin Clemens	Kevin Clemens	Kevin Clemens
PA-TF1	Martyn Nevil		Martyn Nevil
TN-TF1	Anthony Fisher	Anthony Fisher	
TX-TF1	Robert McKee	Billy Parker	Billy Parker
UT-TF1	Trevor Tallon		
	Jens Lund		
VA-TF1	Tom Griffin	Mark Lucas	
VA-TF2	Mark Hundley	Mark Hundley	Mark Hundley
	Jim Ingledue		Jim Ingledue
FEMA US&R Technical Working Group		Dave Hammond*	
National Guard	Michael Benzick	Michael Benzick	

* participated via teleconference

APPENDIX B – COMPLETE INITIAL REQUIREMENTS LIST

The following table lists all of the requirements captured during the course of three workshops held with FEMA Task Force members. The Wave 1 candidates for standardization are starred. Red font for a requirement number indicates the Tier 1 list, which met the criteria described in Chapter 2. Green font for a requirement number indicates the Tier 2, which were elevated to Wave 1 based on other rationales.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
1	Chassis		Tether point	1=Yes, 0=No	Hard point on chassis allows vertical insertion.
2	Chassis		System Component Interoperability	1=Yes, 0=No	Interoperability of task-based requirements beyond Minimum Capabilities. Includes all chassis , payload, and operator interface components.
* 3	Chassis	Illumination	Adjustable	1=Yes, 0=No	
4	Chassis	Structural	Shoring	1=Yes, 0=No	Typically providing vertical support.
5	Communications		Expandable Bandwidth	# Additional data streams	Will support additional operational components without loss of data transmission rate sufficient to allow each component to perform its function.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
* 6	Communications	Range	Beyond Line Of Sight	Meters	Must be able to ingress specified number of meters in worst case collapse. Worst case is a reinforced steel structure.
* 7	Communications		Security	Scale 1 - 5	System must be shielded from jamming interference and encrypted. Scale defined: 1=None, 3=Command; 5=Both data and command.
* 8	Communications	Range	Line of Sight	Meters	
9	Communications	Data Logging	Status and Notes	1=Yes, 0=No	Ability to pick up and leave notes.
10	Human-System Interaction		Portability	kg	Assumes 1 piece robot
* 11	Human-System Interaction		Initial Training	Hours	Leads to certification. Includes supporting material sufficient for training within the specified period.
* 12	Human-System Interaction		Proficiency education	Hours annually	Structured environment. Maintains certification.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
* 13	Human-System Interaction		Operator ratio	Number of operators	Per robot
* 14	Human-System Interaction		Acceptable Usability	Effectiveness (percent)	Percent of timed tasks users can successfully complete.
15	Human-System Interaction	Assistive	Unattended sampling	1=Yes, 0=No	Ability to set an interval between sampling during dwell time.
16	Human-System Interaction	Assistive	Auto Notification	1=Yes, 0=No	System notifies operator when conditions arise that need attention.
17	Human-System Interaction	Assistive	Path Tracing	1=Yes, 0=No	Repetitive traversing an operator defined path in relative meters from an operator defined path. True 3D. Within the operating environment.
18	Human-System Interaction	Assistive	Auto Station Keeping	# of Axis	Maintaining Pose (position plus orientation) relative to an operator defined target.
19	Human-System Interaction	Assistive	Emergency stop	1=Yes, 0=No	Immediately upon loss of communications or on operator command.
20	Human-System Interaction	Assistive: Mobility	Reacquire communications	1=Yes, 0=No	

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
21	Human-System Interaction	Assistive: Mobility	Self Extraction	1=Yes, 0=No	Extraction means autonomous ability to regain operational availability.
22	Human-System Interaction	Assistive: Victim Indicators	Probability of Detection	Percent	Must be able to detect live victims.
23	Human-System Interaction	Context	Remote information sharing	Meters	Real time, with personnel not co-located.
24	Human-System Interaction	Context	Operator disengagement	1=Yes, 0=No	Ability to break tether to system.
25	Human-System Interaction	Context	Co-located information sharing	1=Yes, 0=No	
* **26**	Human-System Interaction	Context	Lighting Conditions	Scale 1 - 5	Must be able to view operator console in different lighting conditions. Special emphasis on no light and glare. Scale defined: 1=Complete darkness; 3=Daylight without direct glare; 5=Direct glare on interface.
27[1]	Human-System Interaction	Context	Mobility	Scale 1 -5	Scale; 1=System requires stationary operation; 3=System is portable but can't be used while moving; 5=System

[1] Note that numbering is discontinuous due to preservation of legacy requirements information

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
					can be used while moving on foot.
* 29	Human-System Interaction	Context	Protective Clothing	Scale 1 - 5	Scale: 1=No protection; 3=Minimum protection (threshold); 5=Complete protection (Objective) while maintaining acceptable usability
* 30	Human-System Interaction	Display	Dashboard	1=Yes, 0=No	General chassis system health and status. (e.g. orientation, communications signal strength, power level). Two types of information: Organic: 1) Health--power, motor, sensor. Comm--radio transmission, reception. 2) Pose--location; absolute (x,y,z) or relative. 3) Constraint--inhibitors, manipulator problems, sensing-occluded, blocked. External: 1) Payload sensors
31	Human-System Interaction	Display	Mission data Integration	1=Yes, 0=No	Includes all add-on sensors.
32	Human-System Interaction	Interaction	Component controls	1=Yes, 0=No	To include diagnostics.
33	Human-System Interaction	Interaction	Adjustable noise filtering	1=Yes, 0=No	

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
* 34	Logistics	Cache Packaging	Weight	kg	Per container
* 35	Logistics		MTBF	Hours	Mean Time Before Failure (MTBF) of integrated components. Failure means requires major repair.
* 36	Logistics	Cache Packaging	Setup Time	Minutes	Time from on-site delivery to operation.
37	Logistics		Shock resistance	Pass Drop/Vibration Tests	Organic chassis without mission specific components. Organic includes directional audio, position sensors.
* 38	Logistics	Cache Packaging	Volume	Scale 1 - 5	Scale defined: 1=Pelican 1650 box; 3=Hardigg box checkable on commercial aircraft; 5=Ropack model 4048, 4039 with drop door
* 39	Logistics	Field Maintenance	Spares and Supplies	Percent of robot weight	Field maintenance, performed at base. Self-sustaining operations for 72 hours.
* 40	Logistics	Field Maintenance	Duration	Minutes	Field maintenance, performed at base. Amount of time required to perform routine maintenance operations in the field.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
* 41	Logistics	Field Maintenance	Tools	Scale 1 -5	Field maintenance, performed at base. Scale Defined: 1=Requires special tools, 3=Simple tools (e.g., screw driver), 5= No tools required
42	Logistics	Field Maintenance	Intervals	Scale 1 - 5	Mean time between field maintenance, performed at base Scale defined: 1=12 hours; 3=24 hours; 4=72 hours; 5=10 days
43	Mobility	Aerial	Area of coverage	sq m/hr	Reconnaissance and Surveillance.
44	Mobility	Aerial	Station keeping	# of Axis	Maintaining Pose (position plus orientation) relative to an operator defined target.
45	Mobility	Locomotion	Sustained speed-Soft	km/hr	
46	Mobility	Locomotion	Sustained speed-Obstacles	km/hr	
47	Mobility	Locomotion	Sustained speed-Firm	km/hr	

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
48	Mobility	Locomotion	Endurance-Firm	Hours	Endurance at a sustained speed.
49	Mobility	Locomotion	Endurance-Soft	Hours	Endurance at a sustained speed.
50	Mobility	Locomotion	Endurance-Obstacles	Hours	Endurance at a sustained speed.
51	Mobility	Mobility	Tumble recovery within Terrain Type	Scale 1 - 5	Scale defined: 1=None; 3=Self righting; 5=Invertible continuous operations
52	Mobility	Water	Bottom crawler	1=Yes, 0=No	
53	Mobility	Water	Surface swimmer	1=Yes, 0=No	
54	Mobility	Water	Underwater swimmer	1=Yes, 0=No	Not on bottom.
55	Operating Environment		Explosive Environments	1=Yes, 0=No	Meet or exceeds Class I, Division I, Groups A, B, C, D.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
56	Operating Environment		Max Temperature	Degrees C	
58	Operating Environment		Water	Scale 1 - 4	Scale: 1=Not water resistant; 2=Wash down; 3=Submersible; 4=Water resistant to 12 meters.
58	Operating Environment		Min Temperature	Degrees C	
59	Payload	Manipulation	Ability to open doors	1=Yes, 0=No	Internal, external, variety of standard knobs and push doors.
60	Payload	Manipulation	Sensor manipulation	1=Yes, 0=No	Includes reach and dexterity components.
61	Payload	Manipulation	Spray	1=Yes, 0=No	Decontamination, marking, etc.
62	Payload	Manipulation	Max Reach	mm	
63	Payload		Emplacement	1=Yes, 0=No	Vertical, horizontal

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
64	Payload		Delivery	kg at max reach	
65	Payload		Retrieval	mm	Picking up foreign objects at max reach not configured for a robot.
66	Power		Dwell Time	Scale 1 - 5	Amount of time system can remain active but stationary.
* 67	Power		Working Time	Scale 1 - 5	System working time beyond mobility requirements. See Mobility within terrain. Must have sufficient power to operate for specified number of hours. Assumes one power charge. One out and back mission. Scale defined: 1=1 hour; 3=4 hours;5=12 hours
* 68	Power		Sustainment	Hours	Amount of time system must be able to operate in field before re-supply is needed. Scale defined: 1=12 hours; 3=24 hours; 4=72 hours; 5=10 days.
* 69	Power		Runtime Indicator	1=Yes, 0=No	Must be able to inform operator of remaining power level (percent).

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
70	Power		Voltage compatibility with cache	1=Yes, 0=No	Must be adaptable to other power sources in the cache.
71	Sensing		Remote temperature	1=Yes, 0=No	Ability to check temperature of surfaces before taking action
72	Sensing	Audio	2-way	Scale 1 - 5	Scale defined: 1=Volume control. Listen all the time, push to talk; 3=Stereo; 5=Directional indication.
73	Sensing	Hazmat	Hazard Detection	Scale 1 - 5	Scale:1=ph + O2, LEL, CO, H2s, RAD; 2=+WMD and TIC detection;3=+WMD and TIC classification; 4=+Tentative WMD and TIC identification; 5=+WMD and TIC sampling. Detection capabilities must meet current capabilities as documented in industry standards. No lat
74	Sensing	Internal	Orientation reporting	# of Axes	
75	Sensing	Location	Absolute	Scale 1 - 5	Reporting location on available maps or reference points. Scale defined: 1=Topological from start point; 3=1+Mapping onto to local facility floor plans; 5=(1-4)+3D GIS map

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
76	Sensing	Location	Relative	Location accuracy (CEP)	Reporting point location relative to start point. Relative meters means from a known starting point. True 3D. Within the operating environment.
77	Sensing	Location	Absolute accuracy	Meters	
78	Sensing	Mapping	Operator annotations	1=Yes, 0=No	Ability to overlay operator waypoints to mark locations or features of interest.
79	Sensing	Mapping	Equipment set up time	Minutes	Assumes system has been transported to site. Assume 0,0,0 start point. External tracking equipment.
80	Sensing	Mapping	Spatial Modeling	1=Yes, 0=No	Spatial modeling of traversed path.
81	Sensing	Mapping	Waypoint annotation	Scale 1 - 5	Ability to overlay operator waypoints to mark locations or features of interest. Scale Defined: 1=Manual; 3=Manual and automatic; 5=Fully automatic and integrated.
82	Sensing	Passive Data Logging Offboard	Location	1=Yes, 0=No	
83	Sensing	Passive Data Logging Offboard	Hazmat	1=Yes, 0=No	

Requirement Number (starred ones are Wave 1 candidates)	**Type**	**Sub_Type**	**Requirement**	**How Measured**	**Description**
84	Sensing	Passive Data Logging Offboard	Victim Indicators	1=Yes, 0=No	
85	Sensing	Passive Data Logging Offboard	System Health	1=Yes, 0=No	
86	Sensing	Passive Data Logging Onboard	Location	1=Yes, 0=No	
87	Sensing	Passive Data Logging Onboard	Victim Indicators	1=Yes, 0=No	
88	Sensing	Passive Data Logging Onboard	Hazmat	1=Yes, 0=No	
89	Sensing	Passive Data Logging Offboard	Visual	1=Yes, 0=No	
89	Sensing	Passive Data Logging Onboard	Visual	1=Yes, 0=No	
90	Sensing	Passive Data Logging Onboard	System Health	1=Yes, 0=No	

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
91	Sensing	Structural	Void Detection	1=Yes, 0=No	Detecting but not necessarily entering voids.
92	Sensing	Structural	Range Finder	1=Yes, 0=No	Distance to target. Accuracy: +- resolution.
93	Sensing	Victim Indicators	Thermal Imaging	Scale 1 - 5	Scale defined: 1=Industry spec; 3=Military spec; 5=Particularly useful for US&R needs such as structural, leak detection, fire.
94	Sensing	Victim Indicators	Seismic	1=Yes, 0=No	Meet or exceed current Delsar life detection capabilities for both Hz and db.
95	Sensing	Video	Pan	Degrees	Independent of robot mobility.
* 96	Sensing	Video	Real time remote video system (Near)	Range (mm)	
97	Sensing	Video	Pan/Tilt rate	Degrees/sec	
98	Sensing	Video	Pan/Tilt orientation	1=Yes, 0=No	Pan/Tilt orientation indicator.

Requirement Number (starred ones are Wave 1 candidates)	Type	Sub_Type	Requirement	How Measured	Description
* 99	Sensing	Video	Real time remote video system (Far)	Range (meters)	Resolution of the image will be tested using visual acuity tests at given range. Limiting case could be assessment of structural integrity of the building. Image should be in color and resolution. Operator must read eye chart through entire imaging system
100	Sensing	Video	Tilt	Degrees	Independent of robot mobility.
* 101	Sensing	Video	Field of View	Degrees	With macro capability. Maintain clear image, anti fog, low light capability
102	Logistics	Cache packaging	Transportation Restrictions	1=Yes, 0=No	Conforms to existing cache transportation restrictions.
103	Operating Environment		Electrified Environment	1=Yes, 0=No	Concern is interacting with a voltage source and tethered back to operator.

APPENDIX C: TOTAL NUMBER OF VOTES RECEIVED BY EACH REQUIREMENT VERSUS ROBOT/DEPLOYMENT CATEGORY

The table below captures the number of votes for each requirement versus the robot or deployment category. The requirements do not exactly match those listed in Appendix B, as some categories were added after the voting was completed.

For each requirement, Task Forces voted whether it was applicable to each given robot/deployment category. For example, the "Chassis, Tether point" requirement (number 1) was voted applicable to Robot/deployment category 1 by eight Task Forces, and to Robot/deployment category 2 by thirteen Task Forces.

				Robot/Deployment Categories (See Table 3 for Descriptions)												
Type	**Sub-Type**	**Requirement**	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1. Chassis		Tether point	Hard point on chassis allows vertical insertion.	8	13	11	9	11	13	10	6	9	8	8	7	7
1. Chassis		System Component Interoperability	Interoperability of task-based requirements beyond Minimum Capabilities. Includes all chassis, payload, and operator interface components.	9	12	12	6	10	10	8	11	13	12	6	8	8
2. Chassis	**Illumination**	Adjustable		12	13	12	9	10	12	10	9	8	8	8	8	8
3. Chassis	**Structural**	Shoring	Typically providing vertical support.	1	5	4	1	10	3	2	0	0	0	0	0	0
4. Communications		Expandable Bandwidth	Will support additional operational components without loss of data transmission rate sufficient to allow each component to perform its function.	7	12	12	9	10	11	9	10	11	10	8	8	8

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
5. Communications	Range	Beyond Line Of Sight	Must be able to ingress specified number of feet in worst-case collapse. Worst case is a reinforced steel structure.	13	13	13	9	11	13	10	10	12	11	8	8	8
6. Communications		Security	System must be shielded from jamming interference and encrypted. Scale defined: 1=None, 3=Command; 5=Both data and command.	10	13	13	10	10	13	10	12	13	12	8	8	8
7. Communications	Range	Line of Sight		10	11	10	9	8	11	8	11	11	11	6	6	7
8. Communications	**Data Logging**	Status and Notes	Ability to pick up and leave notes.	6	11	12	6	5	10	7	8	9	7	4	5	5
9. Human-System Interaction		Portability	Assumes 1 piece robot	13	11	9	8	9	11	8	9	12	10	7	7	6
10. Human-System Interaction		Initial Training	Leads to certification.	13	13	13	10	11	13	10	12	13	12	8	8	8
11. Human-System Interaction		Proficiency education	Structured environment.	11	13	13	10	11	13	10	12	13	12	8	8	8
12. Human-System Interaction		Operator ratio	Per robot	11	13	13	10	11	13	10	12	13	12	8	8	8
13. Human-System Interaction	**	Acceptable Usability	Percent of tasks users can complete.	10	13	13	10	11	13	10	12	13	12	8	8	8
14. Human-System Interaction	**Assistive**	Unattended sampling	Ability to set an interval between sampling during dwell time.	8	9	10	10	8	9	10	12	12	10	5	5	5

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
15. Human-System Interaction	**Assistive**	Auto Notification	System notifies operator when conditions arise that need attention.	13	12	13	10	10	12	10	11	12	11	6	7	7
16. Human-System Interaction	**Assistive**	Path Tracing	Repetitive traversing an operator-defined path in relative meters from an operator defined path. True 3D. Within the operating environment.	3	10	10	6	8	9	9	9	8	8	8	7	7
17. Human-System Interaction	**Assistive**	Auto Station Keeping	Maintaining Pose (position plus orientation) relative to an operator defined target.	7	9	9	10	10	8	8	9	9	8	6	8	8
18. Human-System Interaction	**Assistive**	Emergency stop	Immediately upon loss of comms or on operator command.	8	9	13	7	8	9	8	8	8	7	6	7	7
19. Human-System Interaction	**Assistive: Mobility**	Reacquire comms		10	12	12	6	9	12	10	12	12	11	7	8	8
20. Human-System Interaction	**Assistive: Mobility**	Self Extraction	Extraction means autonomous ability to regain operational availability.	2	10	11	8	8	10	10	5	5	4	6	5	5
21. Human-System Interaction	**Assistive: Victim Indicators**	Probability of Detection	Must be able to detect live victims.	7	11	9	6	7	10	6	6	6	7	2	3	4
22. Human-System Interaction	**Context**	Remote information sharing	Real time, with personnel not co-located.	8	9	11	6	7	9	7	10	10	10	6	7	6
23. Human-System Interaction	**Context**	Operator disengagement	Ability to break tether to system.	6	12	11	9	10	11	9	6	7	7	6	7	7
24. Human-System Interaction	**Context**	Co-located information sharing		5	10	11	7	7	11	7	10	9	10	4	5	5

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
25. Human-System Interaction	**Context**	Lighting Conditions	Special emphasis on no light and glare.	12	12	13	10	11	13	9	11	10	10	8	8	8
26. Human-System Interaction	**Context**	Mobility	Scale; 1=Stationary; 3=Can't run system while moving; 5=Run system while moving. Moving is assumed to be on foot.	13	12	12	8	11	13	9	12	12	12	8	7	8
27. Human-System Interaction	**Context**	Mobility	Scale Defined: 1=Wearable; 3= 1+operate while moving; 5=1+2+hands free	13	12	12	8	10	12	9	12	12	12	8	7	8
28. Human-System Interaction	**Context**	Protective Clothing	Scale: 1=No protection; 3=Minimum protection (threshold); 5=Complete protection (Objective) while maintaining acceptable usability	11	12	11	8	11	12	9	11	11	11	8	8	7
29. Human-System Interaction	**Display**	Dashboard	General chassis system health and status. (e.g. orientation, comm strength, power level). Two types of information: I. Organic: 1) Health--power, motor, sensor. Comm--radio transmission, reception. 2) Pose--location; absolute (x,y,z) or relative. 3) Constraint--inhibitors, manipulator problems, sensing-occluded, blocked. II. External: 1)	12	12	13	10	10	13	9	12	12	12	8	8	8

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
30. Human-System Interaction	**Display**	Mission data Integration	Includes all add-on sensors.	7	11	13	9	9	12	8	12	12	12	7	8	8
31. Human-System Interaction	**Interaction**	Component controls	To include diagnostics.	7	13	12	9	10	12	9	12	12	12	7	8	8
32. Human-System Interaction	**Interaction**	Adjustable noise filtering		5	12	9	6	5	9	5	4	6	6	2	2	4
33. Logistics		Cache packaging--Weight	Per container	12	13	11	8	10	13	9	10	12	12	8	8	8
34. Logistics		MTBF	Operating hours.	11	12	13	10	11	13	9	12	12	12	8	8	8
35. Logistics		Cache packaging--Setup Time	Time from on-site delivery to operation.	12	12	13	8	11	13	10	12	12	12	8	8	8
36. Logistics		Shock resistance	Organic chassis without mission specific components. Organic includes directional audio, position sensors.	13	12	13	9	11	13	10	8	11	11	7	7	7
37. Logistics		Cache packaging--Volume	Scale defined: 1=Pelican 1650 box; 3=Hardigg box checkable on commercial aircraft; 5=Ropack model 4048, 4039 with drop door	11	12	11	9	10	13	10	10	12	12	8	8	8
38. Logistics	**Field Maintenance**	Spares and Supplies	Self sustaining for 72 hours.	11	12	12	10	10	13	10	12	12	12	8	8	8
39. Logistics	**Field Maintenance**	Duration		10	11	12	9	10	12	9	12	12	12	8	8	8

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
40. Logistics	**Field Maintenance**	Tools	Scale Defined: 1=Requires special tools, 3=Simple tools (e.g., screw driver), 5= No tools required	12	11	13	10	10	12	9	12	12	12	8	8	8
41. Logistics	**Field Maintenance**	Intervals	Mean time between routine maintenance.	10	11	13	9	10	12	9	12	12	12	8	8	8
42. Mobility	**Aerial**	Area of coverage	Recon and Surveillance.	8	8	8	6	7	6	6	12	11	11	5	4	4
43. Mobility	**Aerial**	Station keeping	Maintaining Pose (position plus orientation) relative to an operator defined target.	5	6	8	7	5	6	6	12	11	10	3	4	4
44. Mobility	**Locomotion**	Sustained speed-Soft		6	11	12	7	8	12	9	2	3	3	1	1	2
45. Mobility	**Locomotion**	Sustained speed-Obstacles		4	10	10	7	9	12	9	2	3	3	1	1	1
46. Mobility	**Locomotion**	Sustained speed-Firm		7	11	12	7	9	12	9	2	3	3	0	0	0
47. Mobility	**Locomotion**	Endurance-Firm	Endurance at a sustained speed.	5	12	13	7	10	11	9	2	3	3	0	1	1
48. Mobility	**Locomotion**	Endurance-Soft	Endurance at a sustained speed.	4	12	13	8	10	11	9	2	3	3	1	0	1
49. Mobility	**Locomotion**	Endurance-Obstacles	Endurance at a sustained speed.	4	12	11	9	9	11	9	2	3	3	1	1	1
50. Mobility	**Mobility**	Tumble recovery within Terrain Type	Scale defined: 1=None; 3=Self righting; 5=Invertible continuous operations	11	12	10	8	10	13	9	3	5	5	3	3	4

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
51. Mobility	**Water**	Bottom crawler		4	5	4	0	5	5	4	1	0	0	2	7	1
52. Mobility	**Water**	Surface swimmer		0	0	0	0	0	0	0	0	0	0	4	1	7
53. Mobility	**Water**	Underwater swimmer	Not on bottom.	0	0	0	0	0	0	0	0	0	0	6	2	3
54. Operating Environment		Explosive Environments	Meet or exceeds Class I, Division I, Groups A, B, C, D.	11	11	11	10	11	11	10	8	9	9	1	0	1
55. Operating Environment		Max Temperature		11	12	13	9	11	13	10	11	12	12	7	6	7
56. Operating Environment		Water	Scale: 1=Not water resistant; 2=Wash down; 3=Submersible; 4=Water resistant to 12 meters.	11	12	13	8	11	13	10	10	11	11	8	8	8
57. Operating Environment		Min Temperature		10	9	12	9	10	10	9	11	11	12	7	6	6
58. Payload	**Manipulation**	Ability to open doors	Internal, external, variety of standard knobs and push doors.	0	10	9	1	3	2	4	0	0	1	0	0	0
59. Payload	**Manipulation**	Sensor manipulation	Includes reach and dexterity components.	0	9	13	1	6	6	7	2	0	2	4	5	5
60. Payload	**Manipulation**	Spray	Decon, marking, etc.	0	10	10	1	4	5	7	1	0	1	0	0	0
61. Payload	**Manipulation**	Max Reach		0	8	9	4	5	2	6	3	0	1	3	4	3
62. Payload		Emplacement	Vertical, horizontal	2	9	11	6	9	7	8	5	9	8	5	6	4

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
63. Payload		Delivery		2	11	12	5	8	9	9	7	10	10	7	7	5
64. Payload		Retrieval	Picking up foreign objects at max reach not configured for a robot.	0	11	11	3	6	5	8	4	1	5	6	7	6
65. Power		Dwell Time	Amount of time system can remain active but stationary.	10	11	11	9	11	11	10	10	11	10	8	7	7
66. Power		Working Time	Must have sufficient power to operate for specified number of hours. Assumes one power charge. One out and back mission.	12	12	13	9	11	13	10	12	13	12	8	8	8
67. Power		Sustainment	Amount of time system must be able to operate in field before re-supply is needed.	10	12	12	9	11	13	10	12	12	12	8	8	8
68. Power		Runtime Indicator	Must be able to inform operator of remaining power level (percent).	11	12	13	10	11	13	10	12	12	12	8	8	8
69. Power		Voltage compatibility with cache	Must be adaptable to other power sources in the cache.	5	6	7	5	8	8	7	4	5	5	6	5	5
70. Sensing		Remote temperature	Ability to check temperature of surfaces before taking action	7	9	12	8	10	11	8	9	10	10	6	4	4
71. Sensing	**Audio**	2-way	Scale defined: 1=Volume control. Listen all the time, push to talk; 3=Stereo; 5=Directional indication.	10	12	13	8	11	13	9	4	8	7	2	1	4

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
72. Sensing	**Hazmat**	Hazard Detection	Scale:1=ph + O2, LEL, CO, H2s, RAD; 2=+WMD and TIC detection;3=+WMD and TIC classification; 4=+Tentative WMD and TIC identification; 5=+WMD and TIC sampling. Detection capabilities must meet current capabilities as documented in industry standards. No latency	11	13	13	9	10	12	8	11	10	8	1	0	1
73. Sensing	**Internal**	Orientation reporting		6	13	12	7	9	10	9	12	12	11	7	8	8
74. Sensing	**Location**	Absolute	Reporting location on available maps or reference points. Scale defined: 1=Topological from start point; 3=1+Mapping onto to local facility floor plans; 5=(1-4)+3D GIS map	8	9	11	6	8	10	8	9	9	9	5	6	7
75. Sensing	**Location**	Relative	Reporting point location relative to start point. Relative meters means from a known starting point. True 3D. Within the operating environment.	9	10	13	6	10	11	9	11	10	9	6	7	7
76. Sensing	**Location**	Absolute accuracy		5	8	7	4	6	7	6	8	9	7	4	5	5

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
77. Sensing	**Mapping**	Operator annotations	Ability to overlay operator waypoints to mark locations or features of interest.	6	12	12	7	11	11	9	8	9	8	4	4	3
78. Sensing	**Mapping**	Equipment set up time	Assumes system has been transported to site. Assume 0,0,0 start point. External tracking equipment.	8	12	11	8	9	11	9	11	11	11	7	8	8
79. Sensing	**Mapping**	Spatial Modeling	Spatial modeling of traversed path.	5	11	9	4	5	9	8	8	10	7	5	6	5
80. Sensing	**Mapping**	Waypoint annotation	Ability to overlay operator waypoints to mark locations or features of interest. Scale Defined:1=Manual; 3=Manual and automatic; 5=Fully automatic and integrated.	5	10	11	6	9	11	8	10	11	10	5	6	6
81. Sensing	**Passive Data Logging Offboard**	Location		12	12	12	8	10	11	9	12	13	11	7	7	7
82. Sensing	**Passive Data Logging Offboard**	Hazmat		10	12	12	9	10	11	7	12	13	12	5	5	5
83. Sensing	**Passive Data Logging Offboard**	Victim Indicators		9	11	11	8	10	12	7	11	12	11	5	6	5
84. Sensing	**Passive Data Logging Offboard**	System Health		10	12	12	9	11	12	7	12	13	12	8	8	8

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
85. Sensing	**Passive Data Logging Onboard**	Location		6	9	12	6	8	10	6	7	8	5	6	5	5
86. Sensing	**Passive Data Logging Onboard**	Victim Indicators		5	8	11	5	7	8	5	6	5	5	3	2	2
87. Sensing	**Passive Data Logging Onboard**	Hazmat		7	10	12	6	6	8	5	7	5	6	3	2	2
88. Sensing	**Passive Data Logging Onboard**	Visual		7	8	11	5	7	8	4	7	6	6	5	4	4
89. Sensing	**Passive data Logging Onboard**	System Health		7	10	12	7	6	8	5	7	6	6	5	4	4
90. Sensing	**Structural**	Void Detection	Detecting but not necessarily entering voids.	3	11	7	5	9	9	5	1	2	2	0	0	1
91. Sensing	**Structural**	Range Finder	Distance to target. Accuracy: +-resolution.	2	13	10	5	8	9	8	8	7	8	4	3	3
92. Sensing	**Victim Indicators**	Thermal Imaging	Scale defined: 1=Industry spec; 3=Military spec; 5=Particularly useful for US&R needs such as structural, leak detection, fire.	4	11	12	6	8	8	5	7	6	6	2	2	2
93. Sensing	**Victim Indicators**	Seismic	Meet or exceed current Delsar life detection capabilities for both Hz and db.	4	10	7	6	4	6	4	0	2	1	1	1	1
94. Sensing	**Video**	Pan	Independent of robot mobility.	7	13	13	8	8	11	8	10	10	11	6	6	6

Type	Sub-Type	Requirement	Description	Robot/Deployment Categories (See Table 3 for Descriptions)												
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
95. Sensing	**Video**	Real time remote video system (Near)		9	13	12	10	9	12	8	9	8	9	8	8	8
96. Sensing	**Video**	Pan/Tilt rate		5	11	10	6	8	11	7	7	7	8	7	6	6
97. Sensing	**Video**	Pan/Tilt orientation	Pan/Tilt orientation indicator.	7	13	13	6	8	11	7	9	9	10	7	7	7
98. Sensing	**Video**	Real time remote video system (Far)	Resolution of the image will be tested using visual acuity tests at given range.	11	13	13	9	9	12	8	12	11	12	8	8	8
99. Sensing	**Video**	Tilt	Independent of robot mobility.	7	13	13	6	8	11	7	8	8	9	6	6	6
100. Sensing	**Video**	Field of View	With macro capability. Maintain clear image, anti fog, low light capability	11	11	11	10	9	10	8	10	9	10	8	8	8

APPENDIX D - GLOSSARY

The Glossary included herein contains terminology from two different domains that are relevant to the US&R Robot Standards Program: Urban Search and Rescue and Unmanned Systems, which are listed in the following two sections, respectively.

URBAN SEARCH AND RESCUE TERMS AND DEFINITIONS

The following sources were used to obtain the terms and abbreviations. The source document for each is noted.

[1] FEMA US&R-2-FG "Urban Search and Rescue Response System Field Operations Guide" September 2003.

[2] FEMA 9356.1-PR "Urban Search and Rescue Response System In Federal Disaster Operations: Operations Manual" January 2000.

[3] FEMA Emergency Support Function #9 Urban Search and Rescue Annex

[4] DHS SAFECOM Program PSWC&I Statement of Requirements Version 1.0, March 10, 2004

Access control: Both the public safety users as well as the public safety user's device(s) must be authenticated before they are given access to network resources. [4]

ACN: Automatic Call Notification [4]

ACS: American College of Surgeons [4]

Activation: Formal request from DHS/FEMA to a TF via the Point of Contact, that an event has occurred or is projected to occur, that requires mobilization and response for a mission. [1]

Advisory: Formal notification by DHS/FEMA to all TFs that an event is imminent or has occurred but does not require action at this time. [1] Lowest level of notification, used to provide information only. An advisory is issued when conditions have the potential to develop into a disaster. No action is expected of the task force. Advisories provide a means for sharing information concerning incidents, events, or response activities being conducted by other Federal departments and agencies that may or may not result in broader Federal support. [2]

Aerial Port of Debarkation: Arrival airfield in or near the area affected by the disaster or emergency. In the National US&R Response System, also known as the Point of Arrival. [3]

Aerial Port of Embarkation: Departure airfield in the vicinity of a US&R task force's home base. In the National US&R Response System, also known as the Point of Departure. [3]

Affected Area: The area identified in the major disaster declaration which is eligible to receive disaster assistance in accordance with the provisions of Public Law 93-288. Also referred to as the designated area. [2]

After-Action Debriefing Form: Used by the TF managers at the conclusion of a mission to collect and categorize appropriate information. [1]

After-Action Meeting: A formal meeting of the TF personnel assigned to a mission after return from the field. [1]

After-Action Report: Documentation of TF actions and other pertinent information. [1]

Air Mobility Command (AMC): DoD command headquarters at Scott Air Force Base in Illinois. The AMC is the Air Force airlift component responsible for securing transport for task forces and movement to the affected area. [2]

AirLift Control Element (ALCE) : DoD unit that provides command and control for all aircraft loading operations. The ALCE interfaces between the task force and the air base to load all task force cache items on the aircraft. The ALCE also facilitates training and other coordination activities during non-emergency times. An ALCE is part of an AirLift Control Squadron (ALCS). [2]

Alert: Formal notification by DHS/FEMA to identified TFs that a disaster is imminent or has occurred that may result in activation. [1]

Assembly Point (AP): Location or facility where TF members initially report after receiving activation orders from the sponsoring organization. [1]

ATF: Bureau of Alcohol, Tobacco and Firearms [4]

Attack detection and prevention: The communications networks must be resistant to jamming; they must be capable of passive/active attack monitoring and defense deployment; they must be able to geo-locate the source of an attack; and, they must be capable of monitoring of all functional aspects by authorized users/devices [4]

Authorization: Once a user has been granted access to the system, the services and information that the user has access to will be determined by that users' authorization level. [4]

AVL: Automatic Vehicle Location [4]

Base of Operations: TF base camp used to facilitate mission activities. [1]

Base Support Installation: Any military installation of any service or agency designated by the Department of Defense to provide civil authorities with specified, integrated support of disaster operations. The installation is normally located outside, but within relative proximity to, the disaster area. [3]

Cache: A DHS/FEMA-approved complement of tools, equipment, and supplies stored in a designated location, available for emergency use. [1]

CAD-Computer Aided Dispatch [4]

Catastrophic Disaster Response Group (CDRG): Representatives from Federal agencies that have FRP responsibilities. The CDRG's primary role is that of a centralized, coordinating entity available at the call of the Chairperson. Its members have timely access to the policy makers in their respective parent organizations to facilitate decisions on problem and policy issues. [2]

CBR&E-Chemical, Biological, Radiological, and Explosive [4]

CERT-Community Emergency Response Teams: Trained civilian volunteer auxiliary responders that assist victims and provide support for professional responders during a major disaster. [4]

Civilian advisory support: Subject matter experts that will be made available by FEMA to provide technical advice to US&R components during mission operations. [2]

Clear text: An ICS term for use of plain language for radio communications. [2]

Collapse hazard zone: The area established by the TF for the purpose of controlling all access to the immediate area of the collapse. [1]

Commander-In-Chief. Transportation Command (CINCTRANS) : DoD command responsible for air transportation. Also refer to USTRANSCOM. [2]

Continental United States Army (CONUSA): DoD geographic division of the United States into two areas to facilitate the management of Army assets. The two CONUSAs report to CINCFOR (Commander-In-Chief, Forces Command). [2]

Data security: The communication networks must not allow unauthorized interception of communications or information; they must not allow communications replay attacks; and, they must have non-repudiation capabilities to ensure evidence in the event of a dispute. [4]

Day-to-day: Routine or day-to-day operations fit a general normal structure for the public safety personnel and should not tax their ability to deal with communications processes and procedures. Many of these operations may be strictly within the discipline or agency with no communications interoperability requirements with other disciplines or agencies at all. However, as described in the PSWAC Final Report, day-to-day operations can include the need for city law enforcement personnel to communicate with their county law enforcement personnel and vice versa. The ability to communicate minimizes the need for dispatcher-to-dispatcher interaction in the exchange of information among units in the field. Day-to-day operations can also include task force operations to carry out a specific mission, such as a DUI (Driving Under the Influence) stake-out, where the communications are within the agency and do not require interoperability with other agencies. Also on a day-to-day basis, an agency (such as one fire district) can provide mutual aid to another agency (a second fire district) while the first agency covers an emergency. This form of mutual aid is different than the mutual aid interoperability discussed below. [4]

Defense Coordinating Officer (DCO): Federal official located at the DFO reporting to the FCO who facilitates State requests for DoD personnel and supplies through the ESF representatives. The DCO send all requests to DOMS for execution. [2]

Demobilization: The process used to plan for and implement the return of TFs to their original Point of Departure. [1]

Department of Defense (DoD): A branch of the Federal government which is a support agency to ESF #9 - Urban Search and Rescue. [2]

Department of Homeland Security (DHS): The executive department of the United States [whose] primary responsibility is to: (a) prevent terrorism; (b) reduce the vulnerability of the United States to terrorism; (c) minimize the damage, and assist in the recovery, from terrorist attacks that do occur within the United States; (d) carry out all functions of entities transferred to the Department, including by acting as a focal point regarding natural and manmade crises and emergency planning; (e) ensure that the functions of the agencies and subdivisions within the Department that are not related directly to securing the homeland are not diminished or neglected except by a specific explicit Act of Congress; (f) ensure that the overall economic security of the United States is not diminished by efforts, activities, and programs aimed at securing the homeland; and (g) monitor connections between illegal drug trafficking and terrorism, coordinate efforts to sever such connections, and otherwise contribute to efforts to interdict illegal drug trafficking. [1]

Department of Transportation (DOT): Federal department which is a support agency to ESF #9. DOT will provide information on the condition of airfields and ground transportation routes. DoD, as a supporting agency, will also provide transportation support. [2]

Designated area: The area identified in the major disaster declaration which is eligible to receive disaster assistance in accordance with the provisions of Public Law 93-288. Also referred to as the affected area. [2]

DFFP-Department of Forestry and Fire Protection [4]

Directorate of Military Support (DOMS): DoD directorate located in the Pentagon that is the executing agent for the FRP. [2]

Disaster Field Office (DFO): The temporary office established in or near the designated disaster area from which the Federal Coordinating Officer and staff, the Emergency Response Team, the State Coordinating Officer and staff (when possible), and regional response organizations coordinate response activities. [1]

Disaster Medical Assistance Team (DMAT): The basic deployable unit of the National Disaster Medical System, which is administered by the Department of Health and Human Services. Staffed with physicians, nurses, other health care professionals, and support staff, DMAT capabilities include triage and stabilization of patients at a disaster site and provision of austere medical services at transfer points during transport to definitive medical care locations. [3]

DMAT-Disaster Medical Assistance Teams: A mobile medical field unit staffed and equipped to treat large numbers of injured. [4]

DOT - Department of Transportation [4]

Emergency Response Team (ERT): The interagency group assembled to assist the assigned FCO in carrying out his/her disaster response coordination responsibilities. The ERT coordinates the overall Federal disaster response reporting on the conduct of specific operations, exchanging information, and resolving issues related to ESFs and other response requirements. ERT members respond and meet as requested by the FCO. [1]

Emergency Response Team, Advance Element (ERT-A): An advance element of the ERT dispatched by the affected FEMA region to join State emergency management personnel to coordinate Federal assistance. [2]

Emergency signaling: Signals produced by aerosol horns on the US&R work site to address evacuation of the area, cease operations, or quiet the area, and resume operations. Refer to Appendix I – Task Force Communications Procedures. [2]

Emergency signaling: Signals produced by warning devices on the US&R work site to address evacuation of the area, cease operations or quiet the area, and resume operations. [1]

Emergency Support Function (ESF): A functional area of response activity established to facilitate the delivery of Federal assistance required during the immediate response phase of a disaster to save lives, protect property and public health, and to maintain public safety. ESFs represent those types of Federal assistance which the State will most likely need because of the overwhelming impact of a catastrophic or significant disaster on its own resources and response capabilities, or because of the specialized or unique nature of the assistance required. ESF missions are designed to supplement State and local response efforts. [1]

Emergency Support Team (EST): The Emergency Support Team (EST) is organized, using Incident Command System (ICS) functional groupings of management, operations, logistics, information and planning, and administration/finance, for the activation of the EST, of Federal resources, and mission assignments. The EST coordinates requests for additional resources and receives situation reports. [1]

EMT-P-Emergency Medical Technician-Paramedic [4]

Engagement/disengagement: Procedures followed by a TF when beginning or ending operations at a specific work site or assigned area. [1]

EOC-Emergency Operations Center [4]

Equipment Cache List: The FEMA approved list of equipment that a task force is required to possess for operations. The list represents the maximum equipment that should be carried by a task force. [2]

ERT ESF #9 Leader: The position on the ERT that assumes management and coordination of ESF #9 resources when the RST transfers all US&R responsibilities to the ERT and when the IST is operational in the field. The ERT ESF #9 Leader coordinates all US&R activities with the State, the Emergency Services Branch Chief, the IST ESF #9 Assistant, and the EST ESF #9 Leader. [1]

ESF #9 Assistant: The position located with the IST that provides management oversight to the IST. The ESF #9 Assistant coordinates with the EST and ERT ESF #9 cells, the IST Leader, Task Force Leaders, local and State incident management personnel, and supporting ESFs. [1]

ESF #9 cell (at the DFO): DHS/FEMA representatives at the DFO who coordinate State requests for US&R resources. [1]

ESF #9 Group (at the DFO): FEMA representatives at the DFO who coordinate State requests for US&R assets. These individuals coordinate with a State US&R counterpart who is also located at the DFO. The ESF #9 Group sends requests to the IST who directs the task forces to incident locations. [2]

ESF #9 Leader: The individual at DHS/FEMA Headquarters responsible for assessing requests for US&R TFs. [1]
ESF #9 Program Officer: The individual at FEMA Headquarters responsible for assessing requests for the US&R task forces. The ESF #9 Program Officer coordinates closely with the DOMS and the Public Health Service to ensure that task forces are deployed in a timely manner. [2]

ESF #9: National US&R Response System [1]

ESF #9: US&R emergency support function responsible for locating, extricating, and providing initial medical treatment to disaster victims and to conduct other life-saving operations. [2]

EST ESF #9 Leader: The individual at working at the EST responsible for assessing requests for US&R Task Forces, alerting, activating and deploying ESF #9 resources when approved and overseeing ESF #9 mission assignments, staffing, information and planning, and demobilization activities. [1]

Expendable property: The term used to identify items such as small hand tools, gloves, saw blades, batteries, etc., that may normally be consumed or expended during the course of a mission. [2]

Extended Area Network (EAN): Jurisdiction Area Networks that are linked with county, regional, state, and national systems or extended area networks (EAN). [4]

FBI-Federal Bureau of Investigation [4]

Federal Coordinating Officer (FCO): The senior Federal official appointed to coordinate the overall response and recovery activities. The FCO represents the President for the purpose of coordinating the administration of Federal relief activities in the designated area. [2]

Federal Coordinating Officer (FCO): The senior official in charge at the DFO who manages all Federal response activities. [1]

Federal Emergency Management Agency (FEMA): Agency with primary responsibility for ESF #9 (Urban Search and Rescue.) [1]

Federal Response Plan (FRP): The Federal Government's plan of action to assist affected States and local jurisdictions after a major disaster or emergency. [1]

FEMA Regional Action Officer: The individual, operating out of a FEMA regional office, who routinely coordinates with the respective States within the region for US&R program activities and during times of mission deployment. [2]

FEMA-Federal Emergency Management Agency [4]

Field Operations Guide (FOG): A pocketsize document that is carried in the field by US&R personnel. The FOG provides instant access to reference material such as operational checklists, functional procedures, emergency directives, etc. [2]

General Services Administration (GSA): The Federal agency responsible to FEMA for providing on-site support to the US&R task forces for supplies needed after the initial 72 hours of operation. [2]

GPS-Global Positioning System [4]

HAZMAT - Hazardous Materials [4]

HIPAA-Health Insurance Portability and Accountability Act [4]

IAFIS-Integrated Automated Fingerprint Identification System [4]

IC - Incident Command or Incident Commander [4]

ICS Form 205: Radio Communications Plan form for use during mission operations. [2]

IDENT-Immigration and Customs Enforcement Automated Biometric Identification System [4]

Incident Action Plan (IAP): A document developed by the ICS management team that identifies all incident objectives, strategies and tactics, and assigns responsibilities. [1]

Incident Area Network (IAN): An incident area network (IAN) is a network created for a specific incident. This network is temporary in nature. [4]

Incident Command Post (ICP): The location where the local jurisdiction's primary command functions are executed. [1]

Incident command structure: The communications systems must support the agency's incident command policies. [4]

Incident Command System (ICS): Common organizational structure with capability of managing the assigned resources in an effective manner. See NIIMS. [2]

Incident Commander (IC): The local jurisdiction's person responsible for the management of all incident operations. [1]

Incident Daily Briefing Form: A form for conducting planning sessions and briefings during the course of a mission. [1]

Incident stress management: A process for allowing personnel to air their feelings and defuse emotions related to stressful or traumatic disaster-related incidents. [2]

Incident Support Team — Advance Element (IST-A): An advance element of the IST, utilized to conduct needs assessments, provide technical advice and assistance to State and local government emergency managers, and prepare for incoming US&R task force and IST resources. The IST-A reports to the IST Commander. [3]

Incident Support Team (IST): The IST provides a group of highly qualified specialists readily available for rapid assembly and deployment to a disaster area. The IST furnishes Federal, State, and local officials with technical assistance in acquiring and using US&R resources. It provides advice, Incident Command assistance, management, and coordination of US&R Task Forces, and US&R logistics support. [1]

information on the real-time status of emergency medical personnel, resources, hospitals, and patients that is accessible by command personnel, authorized responders, health care facilities, and so on. [4]

Initial Task Force (TF) Briefing Form: A form used by the TFL and management staff during the activation phase of the response. The form highlights pertinent information about the event. [2]

Initial TF Briefing Form: A form developed for use during the activation phase of the response. [1]

Interactive data communications: These communications will provide practitioners with maps, floor plans, video scenes, etc., during an emergency. In the context of the type of communications, interactive means that there is a query made and a response provided. The query and response need not be initiated by a practitioner and can include automated queries/responses. Commanders, supervisors, medical staff, etc., can make more intelligent decisions more efficiently with data from field personnel. Similarly, personnel entering a burning building armed with information about the building, such as contents, locations of stairwells, hallways, etc., can also perform their duties better. [4]

Interactive voice communications: Communications between public safety practitioners and their supervisors, dispatchers, members of the task force, etc., that require immediate and high quality response, with much higher performance demands than those required by commercial users of wireless communications. Commands, instructions, advice, and information are exchanged that often result in life and health situations for public safety practitioners, as well as for the public. [4]

International Search and Rescue Advisory Group (INSARAG): A group of international Search and Rescue (SAR) specialists formed for the purpose of advising the United Nations Department of Humanitarian Affairs on the development of standards that will be adopted and used by all international US&R task forces. [2]

IR-Infrared [4]

IST-Incident Support Team: Provides support to US&R teams with tasking, material, and coordination. US&R teams are task forces equipped with the necessary tools and equipment and the required skills and techniques for the search, rescue, and medical care of victims of structural collapse. [4]

ITS-Intelligent Transportation System [4]

JABS-Joint Automated Booking System [4]

JIC-Joint Information Center [4]

Joint Information Center (JIC) : The physical location where Public Information Officers collocate and form the core of the Joint Information System. [1]

Joint Information System (JIS): The system designed to facilitate the exchange of information. The JIS creates a linkage among all PIOs on the Federal, State, and local levels and with the private sector, news media, and other key offices. [2]

Jurisdiction Area Network (JAN): The JAN is the main communications network for first responders. It is responsible for all non-IAN voice and data traffic. It handles any IAN traffic that needs access to the general network, as well as providing the connectivity to the EAN. [4]

LAN-local area network [4]

Lessons learned: Critique information captured from past experiences, documented, and distributed in an effort to improve program operations. [2]

Load master: Individual responsible for all matters associated with preparing the TF equipment, supplies, and personnel during the palletizing, loading, in-flight logistics, and down-loading of the aircraft. [1]

Local Emergency Operations Center (EOC): Each local jurisdiction will usually have an EOC to coordinate response to and support of moderate to large-scale incidents. Initial damage and needs assessment information is consolidated at this point to determine response needs and State and Federal asset requirements. Authority for the management of a disaster rests with the local officials and/or Incident Leader of the affected jurisdictions. State and Federal response is in support of local requests once local resources and capabilities are overwhelmed. [1]

Local jurisdiction: The affected locality/government that has the mandated responsibility for managing the disaster within its borders or boundaries. [1]

MCC - Mobile Commander Center [4]

MCT-Mobile Computing Terminal [4]

Medical Team Fact Sheet: An informational sheet outlining the capabilities and requirements of the TF Medical Team. [1]

Memorandum of Agreement (MOA): Tripartite written agreement between FEMA, the sponsoring organization for the US&R task force of the National US&R Response System, and the State of the sponsoring organization. The MOA outlines responsibilities of each signatory in the event of an activation of the National US&R Response System. The MOA serves as the basis for reimbursement of task force operational expenditures during activation. [3]

Memorandum of Understanding (MOU): Written agreements developed on site between the IST and jurisdictional incident management personnel to ensure a complete understanding of the scope, nature and requirements of the ESF #9 assignment. [1]

Mobilization Center: A temporary facility used to receive process and support resources/TFs during the mobilization and demobilization phases of a mission. [1]

Mobilization time frame: The time in which a task force is expected to assemble at the POD. Six hours is the identified time frame. [2]

Mobilization: The process used by all organizations, Federal, State, and local, for activating, assembling, and transporting resources requested. [2]

Movement Coordination Center (MCC): A group of representatives of Federal agencies (ESF #4, DOT, DoD, and FEMA) within the EST Operations Section that coordinates the movement of Federal resources. [2]

MSO-Mobile Switching Office [4]

Multicast: Occurs when one device sends data across the network to multiple devices; however, depending on the multicast protocol, only nodes that are on the path from the originating device to the receiving device receive and forward the data. [4]

Mutual aid: This mode describes those major events with large numbers of agencies involved, including agencies from remote locations. Their communications are not usually well planned or rehearsed. The communications must allow the individual agencies carry out their missions at the event, but follow the command and control structure appropriate to coordinate the many agencies involved with the event. [4]

National Disaster Medical System (NDMS): A system under the auspices of NDMS used during natural disasters or emergencies. [1]

National Emergency Coordination Center (NECC): FEMA's office which provides notification to FEMA Headquarters and regional responders of implementation of the plan and performs situation monitoring, alerting, and activation. [2]

National Interagency Incident Management System (NIIMS): An incident management system which consists of five major subsystems. A total systems approach total risk incident management. The subsystems are the ICS, Training, Qualifications and Certification, Supporting Technologies, and Publication Management. See ICS. [2]

National Urban Search and Rescue Response System: The task forces, ISTs, and other personnel and technical teams which respond to disasters under the direction of FEMA as Emergency Support Function #9. [2]

NAWAS-National Warning System [4]

NCIC-National Crime Information Center [4]

NIMS-National Incident Management System [4]

NIRSC-National Incident Radio Support Cache [4]

Non-expendable property: The term used to denote expensive, accountable items such as generators, radios, power tools, technical equipment, etc. [2]

Non-interactive data communications: A one-way stream of data, such as the monitoring of firefighter biometrics and location, which greatly increases the safety of the practitioners. This form of communications also makes the command and control requirements easier when the commander is aware of the condition and location of the on-scene personnel. [4]

Non-interactive voice communications: These communications occur when a dispatcher or supervisor alerts members of a group about emergency situations and/or to share information. In many cases, the non-interactive voice communications have the same mission-critical needs as the interactive service. [4]

NPSTC-National Public Safety Telecommunications Council [4]

OEM-Office of Emergency Management [4]

Office of U.S. Foreign Disaster Assistance (OFDA): The Federal agency responsible for assisting FEMA in requesting international assistance of US&R task forces through the United Nations Department of Humanitarian Affairs. [2]

On site: Term used to refer to the operational area where a task force is assigned. [2]

Operating Site: The location of a structural collapse where US&R operations are being conducted. [3]

Operational checklist: A chronological listing of considerations and/or tasks that the identified user should address when carrying out mission assignments. [1]

Operational period: The time interval scheduled for execution of a given set of US&R actions. [1]

Operational procedures: Documents developed to address strategies and tactics that a TF may be required to address and execute during a mission response. [1]

Operational work area: The area established by the TF for controlling all activities in the immediate area of the work site. [1]

Operations Chief: The position in the Incident Command System that is responsible for managing the overall incident tactical operations and to whom the US&R TFs directly or indirectly report. [1]

Operations Manual: A document in the FEMA National US&R Response System series that describes the operational processes used by task forces. The document draws from the FRP and includes standard operating procedures. [2]

Patient Care Form (PCF): A form used during the mission to document medical information relating to a victim who receive treatment by the task force Medical Team. [2]

Personal Area Network (PAN): A first responder is equipped with wireless devices used to monitor the first responder's physical location, pulse rate, breathing rate, oxygen tank status, as well as devices for hazardous gases detection and voice communications. The devices are all linked wirelessly on a personal area network (PAN) controlled by the first responder's communications device. [4]

Personal property: The term used to denote items that are taken on a mission by task force personnel not provided by the sponsoring organization. [2]

PIO - Public Information Officer [4]

Point of Arrival (POA): The location where responding resources arrive, prior to being transported to a mobilization center or assigned to an affected local jurisdiction. [1]

Point of Contact (POC): Designated official at the Federal, State, and local levels who have the primary responsibility for notification, activation, and acceptance reply for mobilization of task forces. [2]

Point of Departure (POD): Designated location where a TF reports for transport to an incident. [1]

Post-mission critique: A meeting of the task force personnel assigned to a mission and occurs within days after the return home. The critique provides the opportunity for individuals to share experiences and discuss lessons learned. Information from the After-Action Debriefing Form may be used in the post-mission critique. [2]

Primary agency: The Federal agency assigned principal responsibility to manage specific ESFs. Primary agencies are designated on the basis of their having the most authority, resources, capabilities, or expertise relative to accomplishment of the specific ESF. [2]

Privacy: The communications systems must allow only intended and authorized recipients to hear/see/read/modify information as well as follow national and state policies (e.g., Health Insurance Portability and Accountability Act-HIPAA). [4]

Property accountability system: A plan for tracking and managing task force tools, equipment, and supplies during all phases of a mission. [2]

PSAP-Public Safety Answering Point: The answering center for 9-1-1 calls. [4]

PSCD-Public Safety Communications Devices: A term developed for the public safety operational scenarios, the PSCD is a portable (handheld or wearable) wireless communications device. [4]

PSTN-Public Switched Telephone Network: The public telephone system. [4]

PSWAC-Public Safety Wireless Advisory Committee [4]

Public Information Officer (PIO): An individual assigned responsibility for collecting and disseminating information related to an incident. The PIO coordinates all media activities associated with the incident. [2]

RACES: Radio Amateur Civil Emergency Service [4]

Regional Operations Center (ROC): Serves as the initial POC for the affected State, other Federal agencies, and EST. The ROC ceases to be a coordinating center once the DFO is established. The ROC is located at the FEMA regional office responsible for the affected State or at a location identified by the FEMA regional staff. [2]

Regional Support Team (RST): Entity that serves as the initial point of contact for the affected State(s), other Federal agencies, and the Emergency Support Team. The RST ceases to be a coordinating center once the DFO is established. [1]

Responder Information Sheet: A form to list all necessary information on task force personnel. [2]

Reverse 9-1-1: REVERSE 911 ® is a Microsoft Windows ® -based program that uses a patented combination of database and GIS technologies that can target a precise geographic area and saturate it with thousands of calls per hour. The software can also create a list of individuals with common characteristics (such as a Neighborhood Crime Watch group or emergency personnel) and contact them rapidly whenever necessary. [4]

Safety Officer: an individual assigned the primary responsibility of safety compliance. [1]

Search assessment marking: A distinct marking system used by task force personnel that denotes information relating to the location of victims. It is used in conjunction with the structural/hazard evaluation marking system. [2]

Self-sufficiency: The capability of a task force to operate in a totally independent fashion. The FEMA standard for self-sufficient capability is for 72 hours. [2]

Site rehabilitation: Returning a building or grounds to the original condition prior to task force operations. [2]

SNS: Strategic National Stockpiles [4]
Sponsoring Organization: the entity responsible for developing and managing all aspects of a TF. [1]

Staging Area: A designated area or facility where incoming resources report to and receive their tactical assignments and situation briefings by the local jurisdiction. [1]

State Coordinating Officer (SCO): The person appointed by the Governor of the affected State to coordinate State and local response efforts with those of the Federal government. [2]

Support agency: A Federal department designated to assist a primary agency. [2]

System administration of users: The communications systems must allow authorized system administrators as well as incident and branch commanders to establish user profiles for network access and usage, depending upon the role that the public safety user is asked to satisfy during an incident. [4]

System to Locate Survivors (STOLS): An acoustic listening device used by specially trained personnel from the U.S. Army Corps of Engineers for the location of victims trapped in collapsed structures. [3]

Task Force Control Center (TFCC): Central control point within the task force Base of Operations used as a focal point by the task force for maintaining communications with elements of the task force. [2]

Task force: A tactical component of the FRP under ESF #9 - Urban Search and Rescue, composed of 62 persons (refer to the FEMA US&R Task Force Description Manual). [2]

T-Card System: A resource tracking system using different color cards displayed in a folder or hanging rack. [2]

Temporary network: JANs and EANs are networks that exist at all times whereas the IANs are created on temporary basis to serve a particular purpose, such as an incident and then are dissolved. The nature of the IAN is such that it may not reach all areas of an incident. In such cases, the user would either connect to the JAN, or create a temporary network to extend the IAN to the area not covered. [4]

TF Base of Operations Locations Checklist: A form to assist task force personnel when selecting a location for set up of their BoO. [2]

TF Command Post (TFCP) : Central control point within the TF BoO. [1]

TF Fact Sheet: summarizes the composition, capabilities and limitations, and support requirements of a US&R TF. [1]

TF Medical Team Fact Sheet: A form that summarizes the capabilities of the task force Medical Team. This form can be used when briefing the local officials. [2]

TF Operations Report: A form for documenting events during the execution of rescue operations. [1]

TF: Task force. [2]

TFL's Mission Assignment Checklist: A form for use by the TFL that identifies important information during the initial briefing provided by the local Incident Commander. [2]

Time-Phased Force Deployment Data (TPFDD): An electronic file that describes the task force in terms of number of personnel and equipment in weights and cubic feet. [2]

U.S. Forest Service (USFS): Federal agency that can be tasked by GSA to set up and operate mobilization centers. As a support agency to ESF #9, the USFS may also provide available aircraft, personnel, and equipment. [2]

U.S. Public Health Service (USPHS): An agency within the Department of Health and Human Services. [2]

U.S. Transportation Command (USTRANSCOM): DoD command which coordinates the movement of air assets for moving task forces. [2]

United Nation's Office for the Coordination of Humanitarian Affairs (OCHA): Entity located in Geneva, Switzerland tasked with the overall responsibility for disseminating information and coordination of international disaster relief activities. [2]

Urban Search and Rescue (US&R): The term used to define the strategy, tactics, and operations for locating, providing medical treatment, and extrication of entrapped victims. [2]

US&R TF Fact Sheet: A form that summarizes the composition, capabilities and limitations, and support requirements of a FEMA US&R task force. Used by the TFL when briefing local officials. [2]

US&R-Urban Search and Rescue: A task force equipped with necessary tools and equipment and the required skills and techniques for the search, rescue, and medical care of victims of structural collapse. [4]

USAR: The term used to identify the United States Army Reserve. [2]

User identification and location: The communications systems must provide user identification to others during communications and when required, must provide user geo-location information to incident commanders and other authorized resources. [4]

User/User group: Public safety personnel and resources that are recognized by the system to share communications and information. This implies that traffic related to this user group only traverses the portion of the network necessary to reach all members of particular user group. Each user group can be a permanent unit or a temporary unit created by an authorized user for a particular task. [4]

UNMANNED SYSTEMS GENERIC TERMS AND DEFINITIONS

Adapted from NIST Special Publication 1011 “Autonomy Levels for Unmanned Systems (ALFUS) Framework”

Note: The ALFUS Framework definitions were developed primarily for describing military unmanned systems (UMS). Definitions solely applicable to military systems have been deleted. The original ALFUS definitions contain numerous citations for reference works and explanatory notes. These have not been reproduced. Instead an ‘’ at the end of the definition indicates further references and notes contained in the original document. The interested reader is referred to the original document.*

Adapt to Failures and Operational Conditions: An unmanned system experiencing either system failures or operational conditions that prevent it from continuing its optimal mission profile will react within the confines of its capabilities. Adaptation with respect to capabilities includes hover, orbit, stop, and station keeping. This adaptation is performed by the system until the condition is cleared or by the operator. System requirements may mandate that the unmanned system continue to perform the mission in a degraded mode.

Autonomous: Operations of an **unmanned system** (**UMS**) wherein the **UMS** receives its **mission** from the human and accomplishes that **mission** with or without further **human-robot interaction (HRI**). The level of **HRI**, along with other factors such as mission complexity**,** and environmental difficulty, determine the **level of autonomy** for the **UMS**. Finer-grained autonomy level designations can also be applied to the **tasks**, lower in scope than **mission**. *

Associated terms:

> **Fully autonomous:** See under **Mode of Operation**.
>
> **Semi-autonomous:** See under **Mode of Operation**.

Autonomous Collaboration: The ability of a **UMS** to **collaborate** with one or more manned vehicles or **UMS** without the need for an external controlling element**.**

Autonomy: (A) The condition or quality of being self-governing. (B) A **UMS**’s own ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting, to achieve its **goals** as assigned by its human operator(s) through designed **HRI**. Autonomy is characterized into levels by factors including **mission** complexity, environmental difficulty, and level of **HRI** to accomplish the **missions**. *

Associated terms:

> **Autonomy Level or Level of Autonomy:** Set(s) of progressive indices, typically given in numbers, identifying a **UMS**’s capability for performing **autonomous** missions. Two types of metrics are used, **Detailed Model for Autonomy Levels** and **Summary Model for Autonomy Levels**.
>
> **Autonomy Levels for Unmanned Systems (ALFUS):** A general term referring to the autonomy level framework, models, and the level numbers.
>
> **Detailed Model for Autonomy Levels:** A comprehensive set of metrics that represent multiple aspects of concerns, including **mission** complexity, **environmental** difficulty, and level of **HRI** that, in combination, indicate a **UMS**’s **level of autonomy**. This model corresponds to the **Summary Model for Autonomy Levels.**
>
> **Summary Model for Autonomy Levels:** A set of linear scales, 0 through 10 or 1 through 10, indicating the **level of autonomy** of a **UMS**. This model is derived from the **UMS**’s **Detailed Model for Autonomy Levels.**

Built-in Test: Equipment or software embedded in operational components or systems, as opposed to external support units, which perform a test or sequence of tests to verify mechanical or electrical continuity of hardware, or the proper automatic sequencing, data processing, and readout of hardware or software systems.

Classes of UGVs: The Joint Robotics Program (JRP) postulates several classes of **UGV**s, based on weight: *

- Micro: < 8 pounds5
- Miniature: 8-30 pounds
- Small (light): 31-400 pounds
- Small (medium): 401-2,500 pounds
- Small (heavy): 2,501-20,000 pounds
- Medium: 20,001-30,000 pounds
- Large: >30,000 pounds.

Cognizance Levels or **Levels of Cognizance:** The levels of what a **UMS** can know or understand based on its **sensory processing** capability:

- Level 1 – data, or observed data. In initially processed forms after measured by sensors.
- Level 2 – information. Further processed, refined and structured data that is human understandable.
- Level 3 – intelligence, knowledge, combat and actionable information. Further processed for particular mission needs. Directly linked to tactical behaviors.

Collaboration or **Cooperation:** The process by which multiple manned or **unmanned systems** jointly work together by sharing data, such as coordinates of their maneuver(s) and local Common Relative Operational Picture (CROP), or by acquiring intelligence to perform a **mission** synergistically, i.e., perform better than each could have alone. *

Associated term:

> **Coordination:** The ability for **UMS**'s or manned systems to work together harmoniously through common data such as mission or task plans, coordinates of maneuver(s), local CROP, etc. A common way is for a superior to **coordinate** the task execution of the subordinates to accomplish the missions. *
>
> **Control Level** or **Level of Control.** *
>
> **Controlling Element:** The part of a **UMS** that provides a method for a human to control it remotely.
>
> **Cooperation:** See **Collaboration.**
>
> **Coordination:** See under **Collaboration.**

Data Fusion: See **Fusion.**

Detailed Model for Autonomy Levels: See under **Autonomy.**

Dynamic mission planning: See **mission planning.**

Environment: Used as a general reference, environment includes the generic, natural conditions; e.g., weather, climate, ocean conditions, terrain, vegetation, etc. Modified environment can refer to specific induced environments; e.g., dirty battlefield environment, nuclear-chemical biological environment, etc. Environment includes those conditions observed by the system during operational use, standby, maintenance, transportation, and storage. Mission environment includes threat situation or Electronic Order of Battle (EOB), Rules of Engagement (ROE), Emission Condition (EmCon), etc.

Fault Tolerance: The ability of a system or component to continue normal operation despite the presence of hardware or software faults. *

Fully autonomous: See under **Mode of Operation**.

Fusion: Also referred to as **Information Fusion** or **Data Fusion.** (A) The combining or blending of relevant data and information from single or multiple sources (sensors, logistics, etc.) into representational formats that are appropriate to support the interpretation of the data and information and to support system goals like recognition, tracking, situation assessment, sensor management, or system control. Involves the process of acquisition, filtering, correlation, integration, comparison, evaluation and related activities to ensure proper correlations of data or information exist and draws out the significance of those correlations. The processes can be performed with a combination of human analysis/judgment and system processing. (B) Information processing that deals with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimation, complete and timely assessments of situations and threats, and their significance in the context of mission operation. The process is characterized by continuous refinement of its estimates and assessments, and by evaluation of the need for additional sources, or modification of the process itself, to achieve improved results. *

Fusion Levels or **Levels of Fusion:** Each of the six levels of fusion adds progressively greater meaning and involves more analysis: *

- Level 0 - organize. This is the initial processing accomplished at or near the sensor that organizes the collected data into a usable form for the system or person who will receive it.
- Level 1 - identify/correlate. This level takes new input and normalizes its data; correlates it into an existing entity database, and updates that database. Level 1 Fusion tells you what is there and can result in actionable information.
- Level 2 - aggregate/resolve. This level aggregates the individual entities or elements, analyzes those aggregations, and resolves conflicts. This level captures or derives events or actions from the information and interprets them in context with other information. Level 2 Fusion tells you how they are working together and what they are doing.
- Level 3 - interpret/determine/predict. Interprets enemy events and actions, determines enemy objectives and how enemy elements operate, and predicts enemy future actions and their effects on friendly forces. This is a threat refinement process that projects current situation (friendly and enemy) into the future. Level 3 Fusion tells you what it means and how it affects your plans.
- Level 4 - assess. This level consists of assessing the entire process and related activities to improve the timeliness, relevance and accuracy of information and/or intelligence. It reviews the performance of sensors and collectors, as well as analysts, information management systems, and staffs involved in the fusion process. This process tells you what you need to do to improve the products from fusion level 0-3.
- Level 5 - visualize. This process connects the user to the rest of the fusion process so that the user can visualize the fusion products and generate feedback/control to enhance/improve these products.

Goal: A result (or state) to be achieved or maintained. *

Hazard Avoidance: Similar to **obstacle avoidance** except that the subjects are not limited to physical objects but also include adversarial situations, as either assessed by the **UMS**'s perception functions or provided through the **HRI**, that are to be avoided.

Human/Operator Intervention: The need for **HRI** in a normally **fully autonomous** behavior due to some extenuating circumstances. An unanticipated action or input by the user to help complete a task.

Human robot coordination: See **coordination.**

Human Robot Interaction/Interface (HRI): Also referred to as **human interaction** or **operator interaction.** (A) The activity by which human operators engage with **UMS**s to achieve the **mission goals**. (B) The architecture for interaction between the robot and the human. It includes the specification of the interaction language: what tasks the user can ask of the robot and the corresponding actions, what tasks the robot can ask of the user and the corresponding actions. It is independent of a particular display or interaction modality. It is the planned and anticipated interactions between the robot and the user. (C) **Human Robot Interface** is further used to reference the physical realization of the method of **Human Robot Interaction** or **Intervention**. The following are the different roles of interaction possible for the human in **HRI**. Note that one person could possibly assume a number of roles or numerous people could take individual roles or even share roles. The user interface should be based on the types of roles the user will assume. In addition to specific information needed for each role, the user will need some awareness of other roles simultaneously interacting with the robot.

> **Supervisor:** the supervisor monitors one or more robots with respect to progress on the mission, can task the robot(s) at the mission level, monitors mission progress, provides mission level directions, coordinates missions, and can assign an operator to assist a robot if needed. A commander would be an example of a person who performs the supervisor-only role.
>
> **Teammate/Wingman:** this is considered to be a human team member. **UMS** and its **teammate** each performs part of the overall mission and they coordinate when needed. The teammate may command the **UMS** at the levels of detail of **tasks** or **task** plans.
>
> **Operator:** the role assumed by the person performing **remote control** or **teleoperation, semi-autonomous** operations, or other man-in-the-loop types of operations. The operator input is expected at certain states during normal operations. During error conditions, the operator determines the problem that a robot is experiencing in interacting with the physical world, interacts with the robot to solve this if possible and returns control to the supervisor with an outcome, successful or not. If the operator cannot overcome the problem it may be necessary to pass the robot control to the mechanic.
>
> **Mechanic** or **Developer:** determines the problem with the hardware or software that the robot is having, solves this if possible, may interact with the robot to test out the proposed solution, and returns control of the robot to the supervisor with a determination.
>
> **Bystander:** coexists in the same environment as the **UMS** but with an unknown role. The bystander role could be neutral, friendly, or adversarial, or include various combinations. The bystander and the **UMS** need to build up some expectation of what the counterpart will do in order to react accordingly. For example, the driver, a **bystander**, of a car may have to interact at a four way stop with a UMS. They both need some indication as to whether the other vehicle knows the rules of the road. Pedestrians and traffic police would be examples of bystanders who would have limited interaction with autonomous driving vehicles. **UMS** needs to be able to protect itself from possible harm from adversarial **bystander**.

Human Operated: The type of **HRI** that refers to **remote control** or **teleoperation**.

Human Assisted: The type of **HRI** that that refers to situations during which human interactions are needed at the level of detail of **task** plans, i.e., during the execution of a task.

Human Delegated: The type of **HRI** that refers to situations during which human interactions are mainly at the **task** level.

Human Supervised: The type of **HRI** that refers to situations during which humans play the monitoring role and human interactions are mainly at the mission level.

Information Fusion: See **Fusion.**

Leader Follower: See **Robotic Follower.**

Markers (physical or electronic) : A visual or electronic aid used to mark a designated point for such tactical purposes as route following, determination of bearings, courses, or location, and key items or points of interest, including landmine markers, minefields markers, and area NBC decontamination markers. Traffic signs and signals are additional examples of **Markers**.

Methods of Control: The interface, either software or hardware, such as a joystick, waypoint selection via a map interface, natural language, hand signals, etc., that operators use to control a **UMS**.

Mission: The highest-level **task** assigned to the **UMS**. *

Mission Module: A self-contained subsystem installed on a **UMS** that enables the **UMS** to perform designed **missions**. It can be easily installed and replaced by another type of mission module. *

Mission Planning: The process to generate tactical goals, a route (general or specific), commanding structure, coordination, and timing for one or teams of **UMS**s. The mission plans can be generated either in advance by operators on an **OCU** or in real-time by the onboard, distributed software systems. The latter case is also referred to as **dynamic mission planning**. *

Mobility: The capability of a **UMS** to move from place to place, with its own power and while under any mode or method of control. Characteristics: the **UMS**'s speed, location, and fuel availability. Refueling could be performed either as a part of the **HRI** or autonomously by a fuel management autonomy task at a higher level. *

Mode of Operation or **Operational Mode:** Human operator's ability to interact with a **UMS** to perform the operator assigned **missions**. The following are the defined **modes of operation**: **fully autonomous, semi-autonomous, teleoperation,** and **remote control.** *

Associated terms:

> **Fully autonomous:** A **mode of operation** of an **UMS** wherein the **UMS** is expected to accomplish its **mission**, within a defined scope, without human intervention. Note that a team of **UMS**s may be **fully autonomous** while the individual team members may not be due to the needs to coordinate during the execution of team missions.
>
> **Semi-autonomous:** A **mode of operation** of a **UMS** wherein the human operator and/or the **UMS** plan(s) and conduct(s) a **mission** and requires various levels of **HRI**. *
>
> **Teleoperation:** A **mode of operation** of a **UMS** wherein the human operator, using video feedback and/or other sensory feedback, either directly controls the actuators or assigns incremental goals, **waypoints** in mobility situations, on a continuous basis, from off the vehicle and via a tethered or radio linked control device. In this mode, the **UMS** may take limited initiative in reaching the assigned incremental goals. *
>
> **Remote control:** A **mode of operation** of a **UMS** wherein the human operator, without benefit of video or other sensory feedback, directly controls the actuators of the **UMS** on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line-of-sight cues. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user. *

Observation: (A) The information collection stage of the "OODA Loop" (Observation, Orientation, Decision, Action); (B) Measurement of the environment by sensors that produce signals that can be analyzed. *

Obstacle: (A) Any physical entity that opposes or deters passage or progress, or impedes mobility in any other way. (B) Any obstruction designed or employed to disrupt, fix, turn, or block the movement of an opposing force, and to impose additional losses in personnel, time, and equipment on the opposing force. Obstacles can be natural, manmade, or a combination of both. They can be positive, negative (e.g., ditches), or groupings (e.g., areas with high security alert) and can be moving or still. *

Operational Mode: See **Mode of Operation.**

Operator Control Unit (OCU): Also referred to as **operator control interface (OCI)** or **human interaction control unit**. The computer(s), accessories, and data link equipment that an operator uses to control, communicate with, receive data and information from, and plan **missions** for one or more **UMS**s. *

Orientation: (A) The stage in the OODA loop (Observation, Orientation, Decision, Action) that involves analysis and prediction and generates information to support decision making stage (B) Rotational displacement between two coordinate frames of reference.

Perception: A **UMS**'s capability of sensing and building an internal model of the environment within which it is operating, and assigning entities, events, and situations perceived in the environment to classes. The classification (or recognition) process involves comparing what it observed with the system's a priori knowledge. *

Associated term:

> **Local perception:** When the perception process has occurred locally onboard the **UMS** and is regarding the **UMS's** local environment and within the **UMS**'s mission context.

Perception Levels or **Levels of Perception**. The progressive results of sensory information after the data have gone through multiple levels of **sensory processing**: *

- Level 1 – point or pixel. A point of concern has physical properties that, quantitatively, can be either measured with the systems' sensor(s) in a one-to-one correspondence or computed over time and space.
- Level 2 – line or list. Groupings of sets of points according to certain criteria, such as continuity in position and direction, over space and/or time.
- Level 3 – surface or boundary. Groupings of sets of contiguous lines or lists according to certain criteria, such as continuity in orientation or curvature, over space and/or time.
- Level 4 – object. Groupings of sets of contiguous surfaces and boundaries according to certain criteria, such as rigid body mechanics, over space and/or time.
- Level 5 – unit of objects. Groupings of sets of objects according to certain criteria, such as density, distribution, and relative positions, motions, and interactions, over space and/or time.

Prognostic Health Management: System using artificial intelligence or other intelligent algorithms and a combination of sensors and models of systems to autonomously react to environmental changes and monitor the operational and maintenance characteristics of the system or systems under consideration. *

Remote Control: See under **Mode of Operation**.

Remotely Guided: An unmanned system requiring continuous input for mission performance is considered remotely guided. The control input may originate from any source outside of the unmanned system itself. This mode includes remote control and teleoperation.

Robot/Robotic: An electro-mechanical system that can react to sensory input and carry out predetermined missions. A robot is typically equipped with one or more tools or certain capabilities, including knowledge so that it can perform desired functions and/or react to different situations that it may encounter [4].

Self-Healing: Automated or semi-automated capability of system repair, covering the infrastructure, hardware, and software aspects. *

Self-Diagnosis: Ability to adequately take measurement information from sensors, validate the data, and communicate the processes and results to other intelligent devices. *

Semi-Autonomous: See under **Mode of Operation.**

Sensor: Equipment that detects, measures, and/or records physical phenomena, and indicates objects and activities by means of energy or particles emitted, reflected, or modified by the objects and activities. *

Sensor Fusion: (A) same as **fusion** except limiting data source to sensors. (B) A process in which data, generated by multiple sensory sources, is correlated to create information and knowledge. Sensor information, when fused, may yield immediately actionable combat information and/or intelligence. The capabilities are of four essential types: Detection, Classification, Recognition, and Identification. *

Sensory Processing: Computing processes that operate on either direct sensor signals or on low level sensory signatures to detect, measure, and classify entities and events and derive useful information, at proper resolutions and at levels of abstractions, about the world. **Sensory processes** can be organized hierarchically with proper relative spatial and temporal resolutions and organized horizontally with assigned but coordinated focuses. There are several ways to organize the progressive sensory processes, to perceive the resulting information, and to structure the knowledge and intelligence:

- **Levels of Fusion:** See **Fusion Levels.**
- **Levels of Perception:** See **Perception Levels.**
- **Levels of Cognizance:** **S**ee **Cognizance Levels.**

Situational Awareness: The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future. In generic terms the three levels of **situational awareness** are level 1, perception, level 2, comprehension, and level 3, projection. There is both individual and group or team **situational awareness**. *

Summary Model for Autonomy Levels: See under **Autonomy.**

Task: A named activity performed to achieve or maintain a goal. **Mission** plans are typically represented with tasks. Task performance may, further, result in subtasking. Tasks may be assigned to operational units via task commands [3].

Task Decomposition: A method for analyzing **missions** and **tasks** and decomposing them into hierarchical subtask structures according to the criteria of command/authority chain, control stability, computational efficiency, and management effectiveness. *

Teleoperation: See under **Mode of Operation.**

Telepresence: The capability of a **UMS** to provide the human operator with some amount of sensory feedback similar to that which the operator would receive if he were in the vehicle. *

Terrain: The physical features of the ground surface, to include the subsurface. These physical features include both natural (e.g., hills) and manmade (e.g., pipelines) features. Major terrain types are delineated based upon local relief, or changes in elevation, and include: flat to rolling, hilly and mountainous. Other important characteristics used to describe the terrain include: hydrologic features (e.g., swamps), vegetation characteristics (e.g., forests) and cultural features (e.g., cities). Complex terrain includes any characteristics or combination of characteristics that make military action difficult. Mobility classes are also used to describe the trafficability of the terrain. The terrain should also be rated as to its trafficability by class of vehicle, this is especially relevant to the use of different classes of UGVs. The three mobility classes are: unrestricted, restricted, and severely restricted. *

Terrain Visualization: A component of battlefield visualization that provides a detailed understanding of the background upon which enemy and friendly forces and actions are displayed. Terrain visualization provides common terrain background for all users and all applications. Additionally, terrain visualization allows interactive planning and mission rehearsal. Terrain visualization includes both natural and man-made features to include impacts of terrain on vehicle speed, maintenance, river-crossing operations, cross-country trafficability, and maneuverability. Terrain visualization includes the subordinate elements of data acquisition, analysis, database management, display and dissemination. Derived from [27].

Tether: A physical communications cable or medium that provides connectivity between an **unmanned system** and its **controlling element** that restricts the range of operation to the length of the physical medium. *

Unattended System: Any manned/unmanned, mobile/stationary, or active/passive system, with or without power that is designed to not be watched, or lacks accompaniment by a guard, escort, or caretaker.

Unmanned System (UMS): A electro-mechanical system, with no human operator aboard, that is able to exert its power to perform designed **missions**. May be mobile or stationary. Includes categories of unmanned ground vehicles (UGV), unmanned aerial vehicles (UAV), unmanned underwater vehicles (UUV), unmanned surface vehicles (USV), unattended munitions (UM), and unattended ground sensors (UGS). *

Waypoint: An intermediate location through which a **UMS** must pass, within a given tolerance, en route to a given goal location. *

World Model: A **UMS'**s internal representation of the world. The world model may include models of portions of the environment, as well as models of objects and agents, and a system model that includes the intelligent **unmanned system** itself. {3}.

Associated term:

> **World Modeling:** The process of constructing and maintaining a **world model**.

Unattended ground sensors (UGS): Small, low cost, robust sensors, capable of operating in the field for extended periods of time (30 days or more). They will consist of modular groups of sensors utilizing tailorable ground sensing technologies, such as seismic, magnetic, infrared, acoustic, radio frequency, and CBRN detection, and other advanced sensing capabilities. UGSs self-organize into a networked sensor array (sensor web) by locating the most efficient gateways for transmission of information. They are also self-healing, able to quickly bypass a neutralized gateway and locate a functional one within the sensor web. *